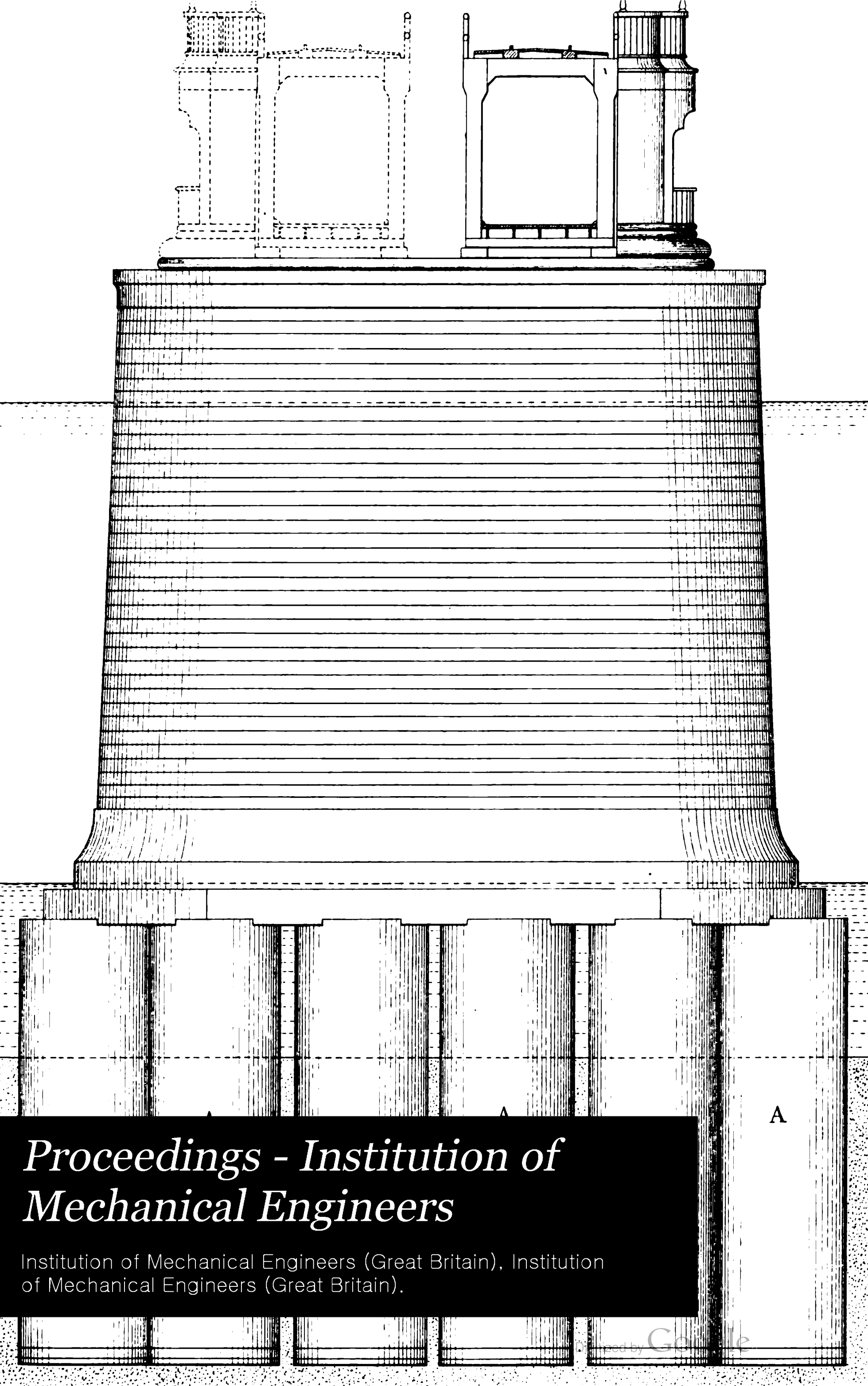

Proceedings - Institution of Mechanical Engineers

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1863.

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1863.

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LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1863.

LIFE MEMBERS.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.
1852. Brogden, Henry, Sale, near Manchester.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven.
1857. Haughton, S. Wilfred, 62 Lower Baggot Street, Dublin.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham.
1853. Maudslay, Henry, Cheltenham Place, Lambeth, London, S.
1848. Penn, John, The Cedars, Lee, Kent, S.E.
1863. Wicksteed, Thomas, 4 Great Queen Street, Westminster, S.W.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Midland Works, Birmingham.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Locomotive Superintendent, Scottish Central Railway, Perth.
1856. Allen, James, Cambridge Street Works, Manchester.
1859. Alton, George, Midland Railway Works, Derby.
1861. Amos, Charles Edwards, Grove Works, Southwark, London, S.E.
1856. Anderson, John, Assistant Superintendent, Royal Gun Factories, and Inspector of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Messrs. Courtney Stephens and Co., Blackall Place Iron Works, Dublin.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.

1858. Appleby, Charles Edward, Mining Engineer, 3 London Terrace, Derby.
1861. Armitage, Harry W., Farnley Iron Works, Leeds.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1863. Armstrong, John, Timber Works, 20 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Great Western Railway, Locomotive Department, Wolverhampton.
1858. Armstrong, Sir William George, Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, Openshaw Works, near Manchester.
1848. Ashbury, John, Openshaw Works, near Manchester.
1858. Atkinson, Charles, Fitzalan Steel Works, Sheffield.

1848. Bagnall, William, Gold's Hill Iron Works, Westbromwich.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1863. Barlow, Edward, Messrs. Dobson and Barlow, Machine Works, Bolton.
1862. Barrow, Joseph, 93 Argyle Terrace, Bristol Street, Hulme, Manchester.
1862. Barton, Edward, 1 Market Street, Manchester.
1847. Barwell, William Harrison, Eagle Foundry, Northampton.
1859. Bastow, Samuel, Cliff House Iron Works, West Hartlepool.
1860. Batho, William Fothergill, Messrs. Nettlefold and Chamberlain, Smethwick Screw Works, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1860. Beale, William Phipson, Westbourne Road, Edgbaston, Birmingham.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington.
1860. Beck, Richard, Lister Works, Upper Holloway, London, N.
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1863. Birckel, John James, Vauxhall Foundry, Liverpool.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1851. Blackwell, Samuel Holden, Russell's Hall Iron Works, near Dudley.

1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1847. Bovill, George Hinton, 24 Duke Street, Westminster, S.W.

1862. Boyd, Nelson, Mining Engineer, Hartington, near Ashbourne.

1854. Bragge, William, Atlas Steel and Iron Works, Sheffield.

1854. Bramwell, Frederick Joseph, 35A Great George Street, Westminster, S.W.

1856. Bray, Edwin, Nevill Holt, near Market Harborough.

1861. Brierly, Henry, 27 Southampton Buildings, London, W.C.

1848. Broad, Robert, Horseley Iron Works, near Tipton.

1863. Brown, Henry, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.

1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1850. Brown, John, Atlas Steel and Iron Works, Sheffield.

1855. Brown, John, Mining Engineer, Barnsley.

1853. Brown, Ralph, Patent Shaft Works, Wednesbury.

1863. Brown, William Steel, Locomotive Superintendent, Edinburgh and Glasgow Railway, Cowlairs, Glasgow.

1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.

1856. Butler, Ambrose Edmund, Kirkstall Forge, Leeds.

1863. Butler, Arthur, Surdah, Radshye, Lower Bengal, India: (or care of Walter Butler, Charing Cross Railway Works, Belvedere Road, Lambeth, London, S.)

1859. Butler, John, Old Foundry, Stanningley, near Leeds.

1859. Butler, John Octavius, Kirkstall Forge, Leeds.

1857. Cabry, Joseph, 39 Marylebone Road, London, N.W.

1847. Cabry, Thomas, North Eastern Railway, York.

1847. Cammell, Charles, Cyclops Steel Works, Sheffield.

1860. Cannell, Fleetwood James, Old Park Iron Works, Wednesbury.

1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1862. Carpmael, William, 24 Southampton Buildings, London, W.C.

1856. Carrett, William Elliott, Sun Foundry, Leeds.

1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.

1849. Chamberlain, Humphrey, 3 St. John's, Wakefield.

1857. Chrimes, Richard, Brass Works, Rotherham.
1854. Clark, Daniel Kinnear, 11 Adam Street, Adelphi, London, W.C.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1859. Clay, William, Mersey Steel and Iron Works, Sefton Street, Liverpool.
1863. Clayton, Robert, Soho Foundry, Preston.
1847. Clift, John Edward, Durnford Place, Coventry Road, Birmingham.
1860. Clunes, Thomas, Vulcan Iron Works, Worcester.
1847. Cochrane, Alexander Brodie, Woodside Iron Works, near Dudley.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesborough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1847. Coke, Richard George, Mining Engineer, 6 Market Hall Chambers, Chesterfield.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1857. Cortazzi, Francis James, Locomotive Superintendent, Great Indian Peninsula Railway, Bombay, India: (or care of T. D. Hornby, 3 Brunswick Street, Liverpool.)
1860. Coulthard, Hiram Craven, Park Iron Works, Blackburn.
1847. Cowper, Edward Alfred, 35A Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., 6 St. John's Road, Putney, London, S.W.
1863. Craig, Andrew, Rock Ferry, Birkenhead.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1858. Crawhall, Joseph, St. Ann's Wire and Hemp Rope Works, Newcastle-on-Tyne.
1857. Criswick, Theophilus, Lydbrook Deep Level Collieries, near Ross.
1863. Crow, George, Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1858. Cubitt, Charles, 3 Great George Street, Westminster, S.W.

1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1862. Deakin, William, Monmer Lane Iron Works, Willenhall, near Wolverhampton.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.

1861. Dixon, Thomas, Low Moor Iron Works, near Bradford, Yorkshire.
1857. Douglas, George K., Messrs. R. Stephenson and Co., South Street, Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Dubs, Henry, 5 Dixon Street, Glasgow.
1856. Dudgeon, John, Sun Iron Works, Millwall, London, E.
1856. Dudgeon, William, Sun Iron Works, Millwall, London, E.
1857. Dunlop, John Macmillan, Marlborough Street, Oxford Street, Manchester.
1854. Dunn, Thomas, Windsor Bridge Iron Works, Manchester.
1861. Dutton, Charles, Bromford Iron Works, Westbromwich.
1860. Dyson, George, Tudhoe Iron Works, near Ferryhill.

1859. Eassie, Peter Boyd, Saw Mills, High Orchard, Gloucester.
1858. Easton, Edward, Grove Works, Southwark, London, S.E.
1856. Eastwood, James, Railway Iron Works, Derby.
1862. Elder, John, Messrs. Randolph Elder and Co., Centre Street, Glasgow.
1859. Elliot, George, Houghton-le-Spring, near Fence Houses.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1857. Evans, John Campbell, Morden Iron Works, East Greenwich, S.E.
1848. Everitt, George Allen, Kingston Metal Works, Adderley Street, Birmingham.

1857. Fairlie, Robert Francis, 56 Gracechurch Street, London, E.C.
1862. Farmer, John, Shut End Iron Works, near Dudley.
1861. Fearnley, Thomas, Globe Works, Hall Lane, Bradford, Yorkshire.
1847. Fenton, James, Low Moor Iron Works, near Bradford, Yorkshire.
1854. Fernie, John, Clarence Iron Works, Leeds.
1862. Field, Joshua, Cheltenham Place, Lambeth, London, S.
1861. Field, Joshua, Jun., Cheltenham Place, Lambeth, London, S.
1861. Fleetwood, Daniel Joseph, Metal Rolling Mills, Icknield Port Road, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Iron Works, Wednesbury.

1847. Fothergill, Benjamin, 27 Cornhill, London, E.C.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1857. Fowler, John, Steam Plough Works, Leeds.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1859. Fraser, John, 18 York Place, Leeds.
1853. Fraser, Joseph Boyes, Alma Place, Kenilworth.
1856. Freeman, Joseph, 22 Cannon Street, London, E.C.
1852. Froude, William, Elmsleigh, Paignton, Torquay.

1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1848. Gibbons, Benjamin, Hill Hampton House, near Stourport.
1860. Gibbons, Benjamin, Jun., Athol House, Edgbaston, Birmingham.
1856. Gilkes, Edgar, Tees Engine Works, Middlesborough.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesborough.
1854. Goode, Benjamin W., St. Paul's Square, Birmingham.
1847. Goodfellow, Benjamin, Hyde Iron Works, Hyde, near Manchester.
1848. Green, Charles, Tube Works, Leek Street, Birmingham.
1861. Green, Edward, Jun., 3 Bank Street, Exchange, Manchester.
1858. Greenwood, Thomas, Albion Works, Leeds.
1857. Gregory, John, Engineer, Portuguese National Railway South of Tagus, Barriero, near Lisbon, Portugal.
1860. Grice, Frederic Groom, Stour Valley Works, Spon Lane, Westbromwich.

1861. Haden, William, Dixon's Green, Dudley.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.
1857. Hall, William, Ashted Varnish and Colour Works, 167 Dartmouth Street, Birmingham.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Millwall Iron Works, London, E.
1858. Harrison, Thomas Elliot, North Eastern Railway, Newcastle-on-Tyne.
1863. Hartas, Isaac, Rosedale Iron Mines, near Pickering, Yorkshire.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1861. Hawkins, William Bailey, 14 George Street, Mansion House, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.

1848. Hawthorn, Robert, Forth Banks, Newcastle-on-Tyne.
1848. Hawthorn, William, Forth Banks, Newcastle-on-Tyne.
1862. Haynes, Thomas John, Engineer and Shipbuilder, Puntales, Cadiz, Spain: (or care of B. G. Haynes, 154 Pailey Road, Glasgow.)
1860. Head, John, Messrs. Ransomes and Sims, Orwell Works, Ipswich.
1858. Head, Thomas Howard, Teesdale Iron Works, Stockton-on-Tees.
1853. Headly, James Ind, Eagle Works, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1862. Heath, William J. W., Assistant Engineer, Ceylon Railway, Colombo, Ceylon: (or care of John J. Heath, 105 Vyse Street, Birmingham.)
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1858. Hedley, John, 4 High Swinburn Place, Newcastle-on-Tyne.
1848. Hewitson, William Watson, Airedale Foundry, Leeds.
1863. Hind, Roger, Scotland Bank Iron Works, Warrington.
1862. Hingley, Samuel, Hart's Hill Iron Works, near Brierley Hill.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Shut End, Brierley Hill.
1863. Holt, Frank, Gorton Foundry, Manchester.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, Tees Side Iron Works, Middlesborough.
1856. Hopkinson, John, London Road Iron Works, Manchester.
1858. Hopper, George, Houghton-le-Spring Iron Works, near Fence Houses.
1858. Horsley, William, Jun., Hartley Engine Works, Seaton Sluice, near North Shields.
1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1860. Howard, James, Britannia Iron Works, Bedford.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1847. Howell, Joseph, Hawarden Iron Works, Holywell.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1862. Huber, Peter Emile, Vogelhutte, Zurich, Switzerland.
1861. Huffam, Frederick Thomas, Avonside Iron Works, Bristol.
1847. Humphrys, Edward, Deptford Pier, London, S.E.
1859. Hunt, James P., Corngreaves Iron Works, Corngreaves, near Birmingham.
1856. Hunt, Thomas, Tudela and Bilbao Railway, Bilbao, Spain: (or 3 Stanley Place, Preston.)
1862. Hunter, Michael, Jun., Talbot Works, Johnson Street, Sheffield.
1860. Hurry, Henry C., Engineer, Great Western Railway, Worcester.
1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.

1857. Inshaw, John, Engine Works, Morville Street, Birmingham.

1859. Jackson, Matthew Murray, Messrs. Escher Wyss and Co., Engine Works, Zurich, Switzerland.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1861. Jackson, Robert, Ætna Steel Works, Sheffield.
1860. Jackson, Samuel, Cyclops Steel Works, Sheffield.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 28A Broadwall, Stamford Street, Lambeth, London, S.
1855. Jeffcock, Parkin, Mining Engineer, Midland Road, Derby.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1857. Jenkins, William, Locomotive Superintendent, Lancashire and Yorkshire Railway, Miles Platting, Manchester.
1861. Jessop, Sydney, Park Steel Works, Sheffield.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, 4 Park Place, Leeds.
1848. Johnson, Richard William, Oldbury Carriage Works, near Birmingham.
1861. Johnson, Samuel Waite, Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1855. Johnson, William Beckett, Woodland's Bank, Altrincham, near Manchester.
1861. Jones, Alfred, Ettingshall Iron Works, Bilston.
1861. Jones, David, Engineer, Rumney Railway, Machen, near Newport, Monmouthshire.
1847. Jones, Edward, Old Park Iron Works, Wednesbury.
1857. Jones, John Hodgson, 26 Great George Street, Westminster, S.W.
1853. Joy, David, Cleveland Engine Works, Middlesborough.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1857. Kennedy, Lt.-Colonel John Pitt, Engineer, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 10 Liverpool Street, New Broad Street, London, E.C.
1848. Kirkham, John, 109 Euston Road, London, N.W.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.

1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1863. Knight, Thomas, 131 Bradford Street, Birmingham.
1862. Knott, Joseph, Pennington Cotton Mill, Leigh, near Manchester.

1863. Lancaster, John, Kirkless Hall Coal and Iron Works, near Wigan.
1863. Latham, Ernest, 40 Parliament Street, Westminster, S.W.
1860. Law, David, Phœnix Iron Works, Glasgow.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Locomotive Superintendent, Monmouthshire Railway and Canal Company, Newport, Monmouthshire.
1860. Lea, Henry, 33 Waterloo Street, Birmingham.
1862. Lee, J. C. Frank, 30 Parliament Street, Westminster, S.W.
1860. Lee, John, Midland Railway, Locomotive Department, Derby.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Miles Platting, Manchester.
1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1856. Levick, Frederick, Cwm-Celyn Blaina and Coalbrook Vale Iron Works, near Newport, Monmouthshire.
1860. Lewis, Thomas William, Plymouth Iron Works, Merthyr Tydvil.
1856. Linn, Alexander Grainger, 2 Queen Square Place, Westminster, S.W.
1857. Little, Charles, Birksland Works, Bradford, Yorkshire.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1862. Lloyd, John, Lilleshall Iron Works, near Wellington, Shropshire.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Old Park Iron Works, Wednesbury.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
1859. Lord, Thomas Wilks, 2A Alfred Street, Boar Lane, Leeds.
1861. Low, George, Millgate Iron Works, Newark.
1854. Lynde, James Gascoigne, Town Hall, Manchester.

1856. Mackay, John, Mount Hermon, Drogheda.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1848. Marshall, Edwin, Britannia Carriage Works, Birmingham.

1862. Marshall, James, Bunker Hill, Fence Houses.
1859. Marshall, William Ebenezer, Sun Foundry, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Stourbridge Water Works, 13 High Street, Stourbridge.
1860. Marten, George Priestley, 13 Morden Road, Blackheath Park, London, S.E.
1853. Marten, Henry, Parkfield Iron Works, near Wolverhampton.
1857. Martindale, Capt. Ben Hay, R.E., War Office, Pall Mall, London, S.W.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1857. Masselin, Armand, 16 Rue Dauphine, Paris.
1853. Mathews, William, Corbyn's Hall Iron Works, near Dudley.
1848. Matthew, John, Messrs. John Penn and Co., Marine Engineers, Greenwich, S.E.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1861. May, Robert Charles, 3 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1860. Mayer, Joseph, Iron Ship Builder, Linz, Austria: (or care of William Seyd, 69 Hatton Garden, London, E.C.)
1859. Maylor, William, East Indian Iron Company, Beypoor, India: (or care of E. J. Burgess, Abchurch Chambers, Abchurch Yard, London, E.C.)
1847. McClean, John Robinson, 23 Great George Street, Westminster, S.W.
1860. McKenzie, James, Well House Foundry, Leeds.
1859. McKenzie, John, Vulcan Iron Works, Worcester.
1862. McPherson, Hugh, Engineer, Gloucester Gas Works, Gloucester.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1857. Metford, William Ellis, Flook House, Taunton.
1847. Middleton, William, Vulcan Iron Foundry, Summer Lane, Birmingham.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.
1853. Miller, George Mackey, Great Southern and Western Railway, Dublin.
1862. Millward, John, Union Chambers, High Street, Stourbridge.
1856. Mitchell, Charles, Iron Ship Building Yard, Low Walker, Newcastle-on-Tyne.
1858. Mitchell, James, 3 Church Terrace, Higher Tranmere, Cheshire.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1849. Morrison, Robert, Ouseburn Engine Works, Newcastle-on-Tyne.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1863. Muir, William, Britannia Works, Manchester.
1857. Muntz, George Frederick, French Walls, near Birmingham.

1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1856. Napier, Robert, Vulcan Foundry, Glasgow.
1861. Natorp, Gustavus, Don Steel Works, Sheffield.
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1856. Newall, James, East Lancashire Railway, Carriage Department, Bury, Lancashire.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Anthony Nichol, 22 Quay, Newcastle-on-Tyne.)
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.

1860. Oastler, William, Engineer, Worcester Gas Works, Worcester.
1847. Owen, William, Messrs. Sandford and Owen, Phœnix Works, Rotherham.

1859. Paquin, Jean François, Locomotive Superintendent, Madrid Saragossa and Alicante Railways, Madrid, Spain.
1860. Parkin, John, Harvest Lane Steel Works, Sheffield.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1848. Pearson, John, 1 Manchester Buildings, 7 Old Hall Street, Liverpool.
1859. Peet, Henry, London and North Western Railway, Locomotive Department, Wolverton.
1861. Perkins, Loftus, 3 Oberhafenstrasse, Hamburg: (or care of A. M. Perkins, 6 Francis Street, Regent's Square, London, W.C.)
1856. Perring, John Shae, 104 King Street, Manchester.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1856. Piggott, George, Birmingham Heath Boiler Works, Birmingham.
1854. Pilkington, Richard, Jun., 17 Tavistock Place, Tavistock Square, London, W.C.
1859. Pitts, Joseph, Old Foundry, Stanningley, near Leeds.
1859. Platt, John, Hartford Iron Works, Oldham.
1862. Player, John, Norton, near Stockton-on-Tees.

1861. Plum, Thomas William, 65 Cannon Street, London, E.C.
1856. Pollard, John, Midland Junction Foundry, Leeds.
1860. Ponsonby, Edward Vincent, Engineer, Great Western Railway, Worcester.
1852. Porter, John Henderson, Ebro Works, Tividale, near Tipton.
1861. Porter, Robert, Ebro Works, Tividale, near Tipton.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.

1862. Rake, Alfred Stansfield, Royal Victoria Dockyard, Passage West, near Cork.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 4 Prince's Terrace, Prince's Gate, London, S.W.
1862. Reynolds, Edward, Don Steel Works, Sheffield.
1863. Richards, Edwin, Pontypool Iron Works, Pontypool.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1863. Richardson, Edward, Engineer, Lyttelton, New Zealand.
1862. Richardson, Robert, 26 Great George Street, Westminster, S.W.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.
1848. Robertson, Henry, Shrewsbury and Chester Railway, Shrewsbury.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Leeds.
1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1860. Rumble, Thomas William, 6 Broad Street Buildings, New Broad Street, London, E.C.
1847. Russell, John Scott, 20 Great George Street, Westminster, S.W.
1863. Ryder, William, Bark Street, Bolton.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1857. Samuelson, Martin, Scott Street Foundry, Hull.
1861. Sanderson, George Grant, Parkgate Iron Works, Rotherham.

1860. Schneider, Henry William, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1858. Scott, Joseph, Messrs. R. & W. Hawthorn, Forth Banks, Newcastle-on-Tyne.

1861. Scott, Walter Henry, Mauritius Railways, Locomotive Department, Port Louis, Mauritius: (or Milton Road, Pewsey.)

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.

1856. Shelley, Charles Percy Bysshe, 21 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1859. Shuttleworth, Joseph, Stamp End Works, Lincoln.

1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.

1862. Siemens, Frederick, 13 Beaufort Road, Edgbaston, Birmingham.

1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.

1862. Simpson, William, Conservative Club, St. James' Street, London, S.W.

1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.

1857. Sinclair, Robert Cooper, 19 Temple Street, Birmingham.

1859. Slater, Isaac, Gloucester Wagon Company, Gloucester.

1853. Slaughter, Edward, Avonside Iron Works, Bristol.

1859. Smith, Charles Frederic Stuart, Mining Engineer, Midland Road, Derby.

1854. Smith, George, Wellington Road, Dudley.

1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.

1858. Smith, Isaac, 36 Lancaster Street, Birmingham.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow, near Ulverstone.

1859. Smith, Matthew, Caledonia Wire Mills, Halifax.

1860. Smith, Richard, The Priory, Dudley.

1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.

1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.

1859. Sokoloff, Capt. Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

1863. Somerville, Wallace Cochrane, Spon Lane Iron Foundry, Westbromwich.

1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)

1859. Spencer, John Frederick, 3 St. Nicholas Buildings, Newcastle-on-Tyne.

1853. Spencer, Thomas, Old Park Works, near Shiffnal.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1857. Stokes, Lingard, 36 Carey Street, Lincoln's Inn Fields, London, W.C.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1861. Sumner, William, 21 Clarence Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1857. Thompson, John Taylor, Messrs. R. and W. Hawthorn, Forth Banks, Newcastle-on-Tyne.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1852. Thomson, George, Crookhay Iron Works, Westbromwich.
1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1862. Tijou, William, 2 Dartmouth Street, Westminster, S.W.
1861. Tipping, Isaac, H. M. Gun Carriage Manufactory, Madras, India: (or care of H. Tipping, Bridgewater Foundry, Patricroft, near Manchester.)
1862. Tolmé, Julian Horn, 19 Duke Street, Westminster, S.W.
1863. Tomlinson, Edward, Miles Platting Works, Elm Street, Manchester.
1857. Tomlinson, Joseph, Jun., Locomotive Superintendent, Taff Vale Railway, Cardiff.
1856. Tosh, George, Locomotive Superintendent, Maryport and Carlisle Railway, Maryport.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1863. Townsend, William, West Orchard, Coventry.

1862. Troward, Charles, Great Northern Railway, Locomotive Department, Doncaster.

1856. Truss, Thomas, Shrewsbury and Chester Railway, Carriage Department, Chester.

1859. Turner, Edwin, Bowling Iron Works, near Bradford, Yorkshire.

1856. Tyler, Capt. Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Company, 146 Goswell Street, London, E.C.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1856. Vernon, John, Iron Ship Building Yard, Brunswick Dock, Liverpool.

1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, New Dock Iron Works, Leeds.

1856. Waddington, Thomas, New Dock Iron Works, Leeds.

1863. Wakefield, John, Great Southern and Western Railway, Locomotive Department, Dublin.

1861. Walker, John G., Netherton Iron Works, near Dudley.

1847. Walker, Thomas, Patent Shaft Works, Wednesbury.

1863. Walker, William Hugill, Wicker Iron Works, Sheffield.

1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Company, Liverpool.

1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Iron Works, Burton-on-Trent.

1862. Watkins, Richard, Canal Iron Works, Millwall, London, E.

1862. Webb, Francis William, London and North Western Railway, Locomotive Department, Crewe.

1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.

1860. Weild, William, Queen's Chambers, Market Street, Manchester.

1862. Wells, Charles, Moxley Iron Works, near Bilston.

1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1859. Whitham, Joseph, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1847. Whitworth, Joseph, Chorlton Street, Manchester.

1852. Whytehead, William Keld, Engineer-in-Chief to the Government of Paraguay: 32 Cambridge Street, Eccleston Square, London, S.W.

1859. Wickham, Henry Wickham, M.P., Low Moor Iron Works, near Bradford, Yorkshire.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, Stocksbridge Iron Works, Deepcar, near Sheffield.
1856. Wilson, Edward, Great Western Railway, Worcester.
1859. Wilson, George, Cyclops Steel Works, Sheffield.
1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.
1852. Wilson, Joseph W., 9 Buckingham Street, Strand, London, W.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 3 Queen Square, Westminster, S.W.
1862. Winby, William Edward, Atherstone.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1863. Wise, Francis, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1858. Wood, Nicholas, Hetton Hall, Hetton, near Fence Houses.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Midland Road, Derby.
1861. Woodhouse, William Henry, 11 Great George Street, Westminster, S.W.
1858. Woods, Hamilton, Messrs. Allsopp and Sons, Burton-on-Trent.
1860. Worssam, Samuel William, King's Road, Chelsea, London, S.W.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1853. Wymer, Francis W., Tyne and Continental Steam Navigation Company, Newcastle-on-Tyne.

1861. Yule, William, Baird's Works, St. Petersburg, Russia.

HONORARY MEMBERS.

1848. Branson, George, Belmont Row, Birmingham.
1863. Brockbank, William, 37 Princess Street, Manchester.
1863. Butler, William, 15 Bilbao Street, Cadiz, Spain.
1851. Clare, Thomas Deykin, Carr's Lane, Birmingham.
1848. Crosby, Samuel, Leek Street, Birmingham.
1863. Fairbairn, John, Farnley Iron Works, Leeds.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Washington, Durham.

1863. Hackney, William, 13 Beaufort Road, Edgbaston, Birmingham.
1860. Hutchinson, William, Blue Lias Lime Stone Offices, Lyme Regis.
1858. Lawton, Benjamin C., 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Member.*)
1860. Manby, Cordy, New Street, Dudley.
1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1856. Pettifor, Joseph, Midland Railway, Derby.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1863. Rigg, Arthur, The College, Chester.
1859. Sherriff, Alexander Clunes, Great Western Railway, Worcester.
1863. Storey, Thomas R., 17 Gracechurch Street, London, E.C.
1848. Warden, William Marston, Edgbaston Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1862. Whitehead, William, Don Steel Works, Sheffield.
1861. Williamson, Alexander W., Ph. D., University College, Gower Street, London, W.C.
1863. Woolley, John, Marehay Colliery, Ripley, near Derby.

GRADUATES.

1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1861. Middleton, Henry Charles, Vulcan Iron Foundry, Summer Lane, Birmingham.
1851. Potts, John Thorpe, 150 Camberwell Grove, London, S.

PROCEEDINGS.

29 January, 1863.

The Sixteenth Annual General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 29th January, 1863; Charles F. Beyer, Esq., in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

ANNUAL REPORT OF THE COUNCIL.

1863.

The Council have much pleasure, on this the Sixteenth Anniversary of the Institution, in congratulating the Members on the very satisfactory progress and prosperous condition of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1862, shows a balance in the Treasurer's hands of £1781 17*s*. 11*d*. after the payment of the accounts due to that date. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1862, and report that the following balance sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with great satisfaction the continued increase in the number of Members that has taken place during the past year; the total number of Members of all classes for the year being 497, of whom 16 are Honorary Members, and 3 are Graduates.

The following deceases of Members of the Institution have occurred during the past year 1862 :—

WILLIAM HAWKES,	Birmingham.
WILLIAM WEALLENS,	Newcastle-on-Tyne.
FRANCIS WRIGLEY,	Manchester.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year, and expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Collection of Engineering Drawings, fifth part; from the Ecole Impériale des Ponts et Chaussées.

Description of the Models, Maps, and Drawings in the International Exhibition of 1862; from M. Cavalier.

Experiments on Wrought Iron and Steel, by David Kirkaldy; from the author.

On the Improvement of the Tyne, by Thomas John Taylor; from Mr. John Taylor.

The Archæology of the Coal Trade, by Thomas John Taylor; from Mr. John Taylor.

On the Resistance of Iron to Projectiles, by William Fairbairn; from the author.

On the Density of Steam, by W. J. Macquorn Rankine; from the author.

Description of an apparatus for Taking off the Waste Gas from Blast Furnaces, by E. Langen; from the author.

Philosophical Transactions and Proceedings of the Royal Society, 6 volumes; from Mr. Walter May.

Journal of the Architect and Engineer's Society for the kingdom of Hannover, from the commencement; from the Society.

Proceedings of the Institution of Civil Engineers; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Transactions of the North of England Institute of Mining Engineers; from the Institute.
Proceedings of the French Institution of Civil Engineers; from the Institution.
Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.
Journal of the Royal United Service Institution; from the Institution.
Transactions of the Institution of Engineers in Scotland; from the Institution.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Memoirs of the Literary and Philosophical Society of Manchester; from the Society.
Report of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.
Transactions of the Royal Scottish Society of Arts; from the Society.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Journal of the Society of Arts; from the Society.
The Engineer; from the Editor.
The Mechanics' Magazine; from the Editor.
The Civil Engineer and Architect's Journal; from the Editor.
The London Journal of Arts; from the Editor.
The Artizan Journal; from the Editor.
The Practical Mechanic's Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Steam Shipping Journal; from the Editor.
Specimen Tube &c. from Hall's Surface Condenser; from Mr. T. Whittaker.

The Council have great satisfaction in referring to the number of Papers that have been brought before the meetings during the past year, and the practical value and interest of many of the communications and the discussions that took place upon them, which form a valuable addition to the proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended, and other subjects advantageous to the Institution.

The following Papers have been read at the meetings during the last year:—

Address of the President, Sir William G. Armstrong.

On a Regenerative Gas Furnace, as applied to Glasshouses, Puddling, Heating, &c.; by Mr. C. William Siemens, of London.

On the Construction of Lighting Apparatus for Lighthouses; by Mr. Armand Masselin, of Birmingham.

On the Coal and Iron Mining of South Yorkshire; by Mr. Parkin Jeffcock, of Derby.

Description of a Feed-pipe Connexion for locomotive engines; by Mr. Alexander Allan, of Perth.

On Surface Condensation in Marine Engines; by Mr. Edward Humphrys, of Deptford.

On the application of the Copying principle in the Manufacture and Rifling of Guns; by Mr. John Anderson, of Woolwich.

On the relations of Power and Effect in Cornish Pumping Engines over long periods of working; by Mr. Charles Greaves, of Bow.

On the Manufacture of Hemp and Wire Rope; by Mr. Charles P. B. Shelley, of London.

On the Construction of Submarine Telegraph Cables; by Mr. Fleeming Jenkin, of London.

On the Double Cylinder Expansive Steam Engine; by Mr. William Pole, of London.

On Double Cylinder Pumping Engines; by Mr. David Thomson, of London.

On the Construction and Application of Iron Armour for Ships of War; by Mr. Norman S. Russell, of London.

On a Packing for Pistons of Steam Engines and Pumps; by Mr. George M. Miller, of Dublin.

On Machinery for the Manufacture of Gunstocks; by Mr. Thomas Greenwood, of Leeds.

Description of a Hydraulic Shears and Punch; by Mr. James Tangye, of Birmingham.

The Council have particular pleasure in referring to the great success and interest of the large and important Meeting of the Institution held in London last summer during the period of the International Exhibition, and in expressing their special thanks to the Local Committee and the Honorary Local Secretary, Mr. Charles Cubitt, for the excellent reception that was given to the Members of the Institution; and also to the authorities of the Government Works

at Enfield and Woolwich for the valuable opportunity afforded to the Members for seeing those works on that occasion. The Council look forward with much confidence to the important advantages arising from the continuance of these Meetings in different parts of the country, from the facilities afforded by them for the personal communication of the Members in different districts of the country, and the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, will go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present annual meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—relative value of radiant surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—steel boilers—incrustation of boilers, and means of prevention—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—circulation of water.

STEAM ENGINES—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves, bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.

BLAST ENGINES, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double cylinder engines, trunk engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—use of coal—consumption of smoke—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

CALORIC ENGINES—engines worked by Gas, or explosive compounds—Electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax and other fibrous materials, both in the natural length of staple and when cut.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, planing, rounding, and surfacing—copying machinery.

LATHES, PLANING, BORING, DRILLING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—comparative strength of drilled and punched plates—rivet-making machines.

Stamping and Coining Machinery, particulars of improvements, &c.

Paper-Making and Paper-Cutting Machines, new materials and results.

Printing Machines, particulars of improvements, &c.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto

Fire Engines, hand and steam, ditto ditto ditto

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto

Cranes, steam cranes, hydraulic cranes, pneumatic cranes, travelling cranes.

Lifts for raising railway wagons—hoists for warehouses—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—power transmitted—method of moulding—strength of iron and wood teeth.

Driving Belts and Straps, best make and material, leather, gutta percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

Dynamometers, construction, application, and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work—drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature, and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—

wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast iron, wrought iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry clay bricks—machines for brick making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFER DAMS AND PILING, facts relating to the construction—cast iron sheet piling.

PIERS, fixed and floating, and pontoons, ditto ditto

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast iron and wrought iron, ditto ditto

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—mode of breaking, pulverising, and sifting various descriptions of ores.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

BLAST FURNACES, consumption of fuel in different kinds—burden, make, and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot blast ovens—pyrometers—means and results of application of waste gas from close-topped and open-topped furnaces.

PUDDLING FURNACES, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

SMITHS' FANS AND FANS generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking—mixtures of coal slack and other materials—evaporative power of different varieties.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought iron, cast iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of solid wrought iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

The communications should be written on foolscap paper, on one side only of each page, leaving a clear margin on the left side for binding, and they should be written in the third person. The drawings illustrating the paper should be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper; or enlarged diagrams should be added for the illustration of any particular portions: the scale of each drawing to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31st December, 1862.

Cr.	£	s.	d.
By Balance 31st December, 1861	1420	9	5
„ Subscriptions from 34 Members in arrear	102	0	0
„ ditto from 441 Members for 1862	1323	0	0
„ ditto from 2 Graduates for 1862	4	0	0
„ ditto from 6 Members in advance for 1863	18	0	0
„ Entrance Fees from 62 New Members	124	0	0
„ Sale of Extra Reports	13	12	0
„ Interest from Bank	33	12	5
	£3038	13	10

Dr.	£	s.	d.	£	s.	d.
To Printing and Engraving Reports of Proceedings	462	7	1			
Less Authors' copies of papers, repaid	52	0	6	410	6	7
„ Stationery and Printing				71	1	8
„ Office Expenses and Petty Disbursements				69	7	9
„ Expenses of Meetings				27	11	8
„ Fittings and Repairs				9	1	8
„ Travelling Expenses				28	18	0
„ Parcels				3	19	2
„ Postages				50	0	4
„ Salaries				450	0	0
„ Rent and Taxes				119	12	6
„ Coals, Gas, and Water				16	16	7
Balance 31st December, 1862				1781	17	11
				£3038	13	10

(Signed) WALTER MAY, EDWARD JONES, Finance Committee.

29th January, 1863.

MEMOIRS

OF MEMBERS DECEASED IN 1862.

William Hawkes was born at Moseley near Birmingham in 1800; and after serving his time with Mr. William Brunton at the Eagle Foundry, Broad Street, Birmingham, became a member of the firm of Messrs. Smith and Hawkes at the same works, in which he continued an active partner up to nearly the time of his death. His health having been declining for more than two years previously, he died on 31st May 1862 at the age of sixty-two. He was elected an Honorary Member of the Institution in 1857.

William Weallens was born on 8th March 1823 at Ponteland near Newcastle-on-Tyne, and was educated at the Grange School, Bishopwearmouth. He acquired his knowledge of mechanical engineering at Messrs. Robert Stephenson and Co.'s works at Newcastle-on-Tyne, where he first became a pupil in 1838, and afterwards succeeded his father-in-law, Mr. William Hutchinson, as resident partner in the firm. He gained considerable reputation as a sound practical mechanic, and was much esteemed by numerous friends and acquaintances for his kindness and geniality of disposition. He was a Member of the Institution from its commencement in 1847, and was for several years a member of the Council. He died at Paris on 2nd Nov. 1862 in the fortieth year of his age, having been taken ill whilst on a journey.

Francis Wrigley was born at Manchester in 1811, and was for some time actively engaged with the firm of Messrs. Sharp Roberts and Co. of that town. In 1841 he went to Russia, and was engaged in the erection of machinery at various cotton and sugar works in that country. He returned to England in 1857, and during the last two years was partner in the firm of Messrs. Fothergill Wrigley and Smith, consulting engineers, Manchester. He became a Member of the Institution in 1859, and died on 2nd Aug. 1862 after an illness of only a few days' duration.

The CHAIRMAN remarked that the very prosperous condition of the Institution and the continued increase in the number of the Members seen from the Report of the Council were highly satisfactory and encouraging, and showed the extended utility of the Institution: he moved that the Report be received and adopted, which was passed.

In accordance with the notice given at the last General Meeting, the following resolution was moved by the Chairman and was passed:—

"That all Members who have filled the office of President of the Institution be ex officio permanent Members of Council, under the title of Past Presidents."

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were duly elected for the ensuing year:—

PRESIDENT.

ROBERT NAPIER,	Glasgow.

PAST PRESIDENTS.

Ex officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG,	Newcastle-on-Tyne.
JAMES KENNEDY,	Liverpool.
JOHN PENN,	London.
JOSEPH WHITWORTH,	Manchester.

VICE-PRESIDENTS.

CHARLES F. BEYER,	Manchester.
ALEXANDER B. COCHRANE,	Dudley.
EDWARD A. COWPER,	London.
JAMES FENTON,	Low Moor.
HENRY MAUDSLAY,	London.
JOHN RAMSBOTTOM,	Crewe.

COUNCIL.

DANIEL K. CLARK,	London.
WILLIAM CLAY,	Liverpool.
JOHN FERNIE,	Derby.
SIR CHARLES FOX,	London.
EDWARD HUMPHRYS,	London.
JAMES KITSON,	Leeds.
SAMPSON LLOYD,	Wednesbury.

Members of Council remaining in office.

Alexander Allan, . . .	Perth.
John Anderson, . . .	Woolwich.
George Harrison, . . .	Birkenhead.
Thomas Hawksley, . .	London.
Robert Hawthorn, . . .	Newcastle-on-Tyne.
Edward Jones, . . .	Wednesbury.
Walter May, ...	Birmingham.
Charles P. Stewart, . .	Manchester.

TREASURER.

Henry Edmunds, . . .	Birmingham.

SECRETARY.

William P. Marshall, . .	Birmingham.

The following New Members were also elected:—

MEMBERS.

Henry Brown, ...	Birmingham.
James Kennan, . . .	Dublin.
Thomas Knight, ...	Birmingham.
Ernest Latham, . . .	London.
Edward Richardson, . . .	New Zealand.
Thomas Wicksteed, . .	London.

The following paper was then read:—

ON THE APPARATUS USED FOR SINKING PIERS FOR IRON RAILWAY BRIDGES IN INDIA.

By Mr. JOSEPH F. STRONG, of Allahabad.

The general mode adopted for forming the foundations for railway bridges over the large Indian rivers is an application of the old native plan of sinking cylinders or wells of brickwork, by excavating the sand from the interior of the cylinders and allowing them to sink by their own weight, increasing the height of each cylinder successively by additional brickwork until it has sunk to a sufficient depth to obtain the required hold in the ground. This plan has been in use for ages in that country for forming the foundations of the native forts on the banks of rivers, and also for sinking wells for water. In the case of the railway bridges the same plan is extended, by being carried out upon a larger scale to obtain a greater depth and consequently greater stability of foundation: sets of brick cylinders, varying in number from three to twelve and in diameter from 18 to 8 feet, based upon wrought iron or wood curbs, are sunk to a sufficient depth in the ground to form the foundations for each pier.

The bridge of which the foundations are described in the present paper is on the main line of the East Indian Railway from Calcutta to Delhi, and spans the river Jumna at Allahabad, about 1¼ mile above its confluence with the Ganges. It is composed of 14 openings of 205 feet clear span each, crossed by wrought iron girders, and giving a total waterway of 2875 feet, the distance between the abutments being 3075 feet; the height of the top of the piers is 58 feet 6 inches and of the rails 80 feet above low water level. Fig. 1, Plate 1, is a general elevation of half the length of the Jumna bridge, and Fig. 2 a transverse section: Fig. 3 gives a section of the bed of the river, the vertical scale being enlarged five times. For the foundations of the bridge ten brick cylinders A A of 13 feet 6 inches diameter are

employed in each pier, sunk to a depth of 43 feet below the low water level, as shown in Fig. 4, Plate 2, which is an elevation of one of the piers taken transversely of the bridge. Fig. 6, Plate 3, is a corresponding sectional plan of the pier, one half being taken through the brick cylinders A A, and the other half through the masonry above them, the outline of the pier being shown by the strong dotted line. Fig. 5 is a vertical section of the pier to a larger scale, taken longitudinally of the bridge, showing a section of a pair of the brick cylinders.

The Jumna, like most of the Indian rivers, winds about much in its course, and varies in width and depth considerably; and within a distance of three quarters of a mile above and below the railway bridge it is 65 and 72 feet deep respectively at low water; but this depth is reduced to only 15 feet at the spot selected for crossing by the chief engineer, Mr. Edward Purser. A number of experimental brick cylinders were sunk to ascertain what the bed of the river consisted of, and at a depth of 35 feet nothing but sand partly mixed with clay was found. Generally speaking the water is so low in the Indian rivers between the months of November and May that there are no great difficulties to be got over in beginning operations for sinking the cylinders to form the foundations of the piers: but in the Jumna, which is never dry, it was unavoidable that the piers had to be begun where there was deep water; and as the means of pitching iron curbs under water were not at hand, the question arose what was the best mode of commencing the building of the cylinders preparatory to sinking them.

The simplest plan seemed to be to form an artificial island for each pier; and this was done in the following manner. Taking the centre of a pier in 15 feet depth of water as the starting point, and setting out a space of 175 feet length by 120 feet width, sand bags were sunk on the down stream and two adjacent sides, thus forming three sides of an enclosure, in the centre of which loose sand was thrown, which was carried by the stream and deposited against the upper side of the lower boundary of sand bags, where it formed a ridge; in due course the surface of the water was thus reached, when the sand was all

thrown on the up stream side, and an island was thereby speedily formed 100 feet long by 60 feet wide at the top. On this island the ten iron curbs were pitched to form the bases for the ten brick cylinders composing the foundations of the pier, being pitched at a distance of 15 feet 6 inches centre to centre transversely of the pier, and 15 feet longitudinally.

The iron curb is shown enlarged in Fig. 7, Plate 4, which gives a vertical section of one of the brick cylinders to a larger scale, showing the cylinder A A partially sunk. The curb B is 13 feet 6 inches diameter outside and 8 feet 6 inches inside, the interior of the brick cylinder diminishing to 6 feet 9 inches diameter. The curb consists of a flat horizontal ring of $\frac{3}{8}$ inch boiler plate, 2 feet 6 inches wide, rivetted by an angle iron to an outer cylindrical ring of similar plate 18 inches deep, and having gusset plates connecting the two rings underneath. The outer cylindrical ring extends 3 inches above the horizontal one, forming a support all round to the base of the brick cylinder on the outside; and an angle iron upon the inner edge of the flat ring forms a similar support within. To keep the curbs in place they are sunk till the top plate of the curb is bedded on the sand; then 12 feet height of brickwork 3 feet $4\frac{1}{2}$ inches thick is built upon the curb, the first 5 feet of which is sunk by simply taking out the sand from the underside of the curb by hand; after which another and quite a different plan of sinking has to be adopted.

The implement generally used for getting out sand &c. in deep foundations in India is called a "jham;" it has been known and used by the natives for ages in sinking wells for water, and also wells for foundations of river forts, quay walls, &c. The jham is a large scoop, something in the form of a large hoe with a short handle, which the natives invariably make of wood, simply having the cutting edge shod with iron. The plan of working they adopted was to send down divers into the water in the interior of the brick cylinder, who with the jham loosened the sand or clay at the bottom; then the diver filled the jham with the loose materials, and was hauled up with it out of the water. This implement was in fact never employed by the natives without the aid of divers who did the excavating work with the jham itself; they

are expert in the use of it, remaining under water regularly about a minute each time of diving. Even in foundations for road bridges built under the direction of government engineers, the jham has been used only in conjunction with divers; and also on the Madras railway, as has been elsewhere described by the chief engineer, Mr. G. B. Bruce, the same means were employed in sinking the brick cylinders for the foundations of the river bridges; the rivers being in that case comparatively small and shallow, and quite dry in the working season.

It is evident that a stronger and more efficient apparatus was needed to sink cylinders 43 feet deep below the water level, through dense sand, as in the case of the large Jumna bridge; and the results of numerous trials with many kinds and forms of the tool gave a jham such as is shown at C in Fig. 7, Plate 4, and Fig. 10, Plate 5. This jham is made of wrought iron with a scoop 2 feet 2 inches wide and 2 feet 4 inches long, made thin and sharp at the front edge, and supported by two stays fixed to the sides of the scoop and also made thin and sharp at their front edges for penetrating the ground readily; the whole weighing about ¾ cwt.

The mode of using this jham is as follows. By means of a couple of ropes D attached to the tail end of the arm E, the jham is lowered by hand to the bottom of the well, till the cutting edge of the scoop C and the outer end of the arm E rest upon the sand, as shown by the full lines in Fig. 7, Plate 4. Then with the weight of two or three men bearing on the top of the vertical pole F, which is held in place by the pin at the bottom passing loosely through a hole in the tail end of the arm E, the scoop is raised a short distance by the ropes D, the outer end of the arm resting upon the sand and forming a sort of centre of motion; and the scoop is then dropped with the weight of the men bearing upon it, and its cutting edge is thus forced into the sand. By repeating these strokes the scoop is forced into the position shown in Fig. 8, Plate 5, the workmen knowing by the feel when the scoop is deep enough in the sand. Then with the weight of the men still on the vertical pole F, the jham is hauled up by means of the windlass G, round the barrel of which the chain is wound that is attached to the extremity of the arm E; the jham being thereby tilted into the position shown in Fig. 9, and brought up filled with sand as shown

dotted in Fig. 7, Plate 4. It requires ten men at the windlass to move the jham when bedded in the sand in the position shown in Fig. 8, and lift it to the position shown in Fig. 9; it is then drawn up to the top, emptied, and the process repeated.

After the first length of 12 feet of brick cylinder has been sunk down to the water level, an additional 15 feet is added, as shown in Fig. 5, Plate 3; and the process of sinking continues till the 15 feet added has been sunk, when an additional 16 feet is added, making a total of 43 feet depth. As a precaution for preventing the curb and lower portion of the brick cylinder from parting from the upper portion, in consequence of the latter being held by the friction of the sand being greater at that part, which is found sometimes to occur, provision is made on the curb for attaching six holding up bolts, which are built into the brickwork for a length of 16 feet, as shown in Fig. 5, Plate 3, and at intervals of every 5 feet a ring of flat iron is dropped over all the bolts and cottered down on to the brickwork.

The rate of sinking of the cylinders is far from regular; at starting the progress is pretty even, the cylinders going down from 15 to 9 inches per day; but the average rate of sinking when down to 20 feet is not more than 4½ inches per day; and beyond that depth the rate of progress gradually decreases till it is not more than 1½ to 1 inch per day of 24 hours. The plan that is adopted where the sinking goes on slowly is to add extra weight on the top of the cylinder, either by building extra brickwork or adding a load of rails. In very bad cases both means are used, till a weight of 40 tons on each cylinder has been added; and even with this additional load on the top great difficulty has been met with when the sinking has reached a depth of 40 feet; which is not surprising when it is considered that there is then a constant pressure due to 40 feet head of water acting upon the sand round the exterior surface of the cylinder at the bottom.

When the cylinders have been got down to the depth of 43 feet they are ready for the concrete H, Fig. 5, Plate 3; but before throwing in the concrete, a diver supplied with Siebe's diving apparatus

is sent down to clear away any rubbish that may be left at the bottom of the well, and level the space under the curbs for the reception of the concrete. A depth of 15 feet of concrete is then thrown in, composed of 1 part of fresh-burnt unslaked lime, 1 of broken bricks, and 2 of underburnt lime; these are the usual proportions of the concrete used in stopping the cylinders, and about 18 days are generally allowed for it to set. A disc made of two thicknesses of 2 inch planking is let down upon the surface of the concrete, weighted by 3 feet thickness of brickwork; this disc is a little less in diameter than the inside of the cylinder, so as to pass freely down on to the concrete, the space between the edge of the disc and the sides of the cylinder being then filled in with wood wedges driven by divers. The object of putting in this disc is to prevent the concrete being disturbed by the pressure of water underneath, whilst the water is being baled out from above the concrete, preparatory to building the cylinder up solid.

The lime used in India is peculiar, and is called "khunkur." It is picked up in the beds of rivers and small streams after the rains, and is found sometimes in isolated beds; but generally it is in detached masses composed of pieces of about the size that stone is broken for metalling roads. It is of a light grey colour, and is burnt in the usual way, either in heaps or in kilns, the latter being preferred; and the percentage obtained is generally about 55 per cent. The mortar used is generally made of 1 part of lime to 1 or 1½ parts of "soorkhee," which consists of bricks pounded and passed through a sieve of 8 meshes to the inch; this mortar is of the best description, being hydraulic, and setting almost better in water than out of it. No sand is found in India sufficiently sharp for making mortar; hence the use by the natives in the first instance, and now by Europeans, of brick-dust, as it may be called, in place of sand for making mortar.

The next operation after having made tight the wood disc upon the top of the concrete is to bale out the water and build up the void inside the cylinder solid with rubble stone, as shown in Fig. 5, Plate 3; this is carried up to the top of the cylinders, and their tops are thus reduced to an even bed ready for the covering stones. As a precaution to prevent these stones from spreading, a groove is cut in the top of the cylinders 6 inches deep and extending lengthways of the pier, as

seen in Fig. 4, Plate 2; into this groove the large stones are laid, and they stretch across the space between the cylinders, and have a good hold on each cylinder. The stones are all cramped at the joints with 1¼ inch square iron, and the stones in the next course above are dropped into joggles in the first course. The hearting of the cylinders is then carried up in brickwork, diminishing by a set-off of 2¼ inches at each course to form a core or centre for the corbelling or over-sailing of the brick steining of the cylinders. A similar provision is made on the outside of the cylinders by throwing in concrete between the cylinders, and building concentric rings of brickwork upon that: over these the corbelling on the outside of the cylinders is carried. There are twelve courses of brickwork between the top of the cylinders and the top of the second course of the covering stones; and at this level there is a through or bonding course of ashlar, running transversely to the piers, as shown in Fig. 5, Plate 3. Up to the top of the plinth there are similar courses faced only with ashlar, the backing or hearting being large rubble. The piers between the plinth and cap are built with ashlar facing to the cutwaters, blocking courses between the shoulders of the cutwaters, and rubble backing behind throughout the whole length of the piers. There are large stones for carrying the cast iron bed plates, upon which the saddles supporting the end standards of the bridge rest.

Fig. 4, Plate 2, shows a complete elevation of one of the piers taken transversely of the bridge, with one of the girders in position and the second one dotted; only one line of rails being at present in process of construction, though all the piers and abutments are made complete for a double line of rails. The general elevation of one half of the complete bridge, shown in Fig. 1, Plate 1, contains seven openings in the half length, of 205 feet clear span each. The girders are wrought iron trusses designed by Mr. George Rendel, in principle something like a double Warren truss, the railway being carried upon the top, and a public roadway upon the bottom of the girders. The girders are constructed with a rectangular box at the top and flat tension bars at bottom; the vertical struts are plain bars with double angle irons, and are clipped between the transverse flanges of the top

box; the diagonal ties are flat bars. In the construction of the girders all the holes are drilled, none being punched. The weight of the pair of girders for one span is for the length of 210 feet between the supports 288 tons, including the cross girders but exclusive of the covering of the roadway and railway; being a weight of 27½ cwts. per foot run.

The section of the river bed, Fig. 3, Plate 1, shows the body of water in the river at low water, and the lower dotted line shows the ordinary rise of the river at flood time, being about 45 feet rise: the level of the underside of the girders is fixed at 14 feet above the ordinary flood level. The upper dotted line shows the extraordinary rise of 51½ feet that took place in the years 1838 and 1861. During the time of the last extraordinary flood of 1861 the current of the river increased to the rate of 9 miles an hour, the ordinary rate when not flooded being only 2 to 3 miles an hour.

Mr. Strong exhibited a model of one of the brick cylinders for forming the bridge piers, showing the construction of the wrought iron curb and the mode of building the brickwork upon it; and also a model of the scoop and windlass used in excavating within the cylinders.

The Chairman asked for some particulars of the materials through which the foundations had to be sunk.

Mr. Strong said that the material to be sunk through was generally sand, but occasionally beds of lime and clay were met with, which however were never either hard or very thick. This process of sinking was not suited for getting through anything much harder than ordinary sand; consequently when lime or stone boulders were met with in sinking it was necessary to send divers down to break up the layer of hard material, so that the pieces could be got up by means of the scoop. When the cylinders had been got down to a depth of 40 feet, the friction produced by the pressure of the sand on the outer

surface of the cylinder was so great and the sand below was so hard that the further progress of the sinking was necessarily slow. Other modes of making foundations in sand had been tried, but the plan now described was the only means that he knew of which had been successfully adopted for sinking brick foundations to any great depth in sand; and he believed the East Indian Railway was the only line upon which the bridge foundations had been sunk in that manner. Iron cylinders, such as had been used for piers in England, were not to be had in India, and the plan adopted appeared to be the only one available under the circumstances.

Mr. H. W. Harman thought the plan of sinking described in the paper appeared quite suitable for sinking foundations in sand; but he considered the apparatus employed would be inadequate for getting up any material of greater density, such as clay. He was at present engaged in some difficult operations of a similar character, in sinking iron cylinders for railway bridge piers in the bed of the Trent near Keadby, and great difficulty had been found in getting through the bed of the river, the interior of the cylinders being kept free of water by maintaining a sufficient pressure of air inside them, and the material excavated being brought up and transferred through the air cell at the top of the cylinder to the outside by hand labour: the process was the same as that employed at Rochester bridge, and was indeed the only one whereby the difficulties met with in such a river could be overcome. In the case of the Indian rivers, as described in the paper, he could easily understand that the sand could be got out very readily by the scoop employed for the purpose: but he was surprised to learn that the progress made was so slow as only 4½ inches depth sunk in 24 hours at a depth of 20 feet, which did not seem to be satisfactorily accounted for. He enquired whether any difficulty had been experienced in keeping the brick cylinders vertical during the sinking, and how that was effected; for if the building of the cylinders were kept up above the surface of the ground, they would be exposed in flood time to a tide running at 9 miles an hour, and in a rapid river great difficulty was found in sinking iron cylinders truly vertical, which would be still greater in the case of brick cylinders built up gradually.

Mr. Strong explained that in the Indian rivers the floods occurred only once a year, and the pier foundations were sunk in the intervening dry season. At ordinary low water the current ran at only 2½ miles an hour, and the cylinders stood up only 7 or 8 feet above the bottom of the river. The means adopted for keeping them vertical in sinking was to move the windlass round through a quarter of a circle every six hours, so as to take the sand with the scoop from every side successively of the interior of the cylinder. In taking the sand from the inside, some of the sand outside necessarily got forced in at the bottom of the cylinder by the external pressure, which had also to be got out by the scoop: and this, with the continually increasing density of the sand, was the reason why the rate of progress diminished so rapidly when the depth sunk was considerable.

Mr. H. Woods asked whether any other plan of getting up the sand had been tried, besides that described, in order to raise it more quickly. He had made about six years ago for Mr. Ward a set of machines like vertical dredgers, intended to be used on some of the railways in India for getting up the sand in sinking pier foundations, and he believed it was intended to use ten of the machines at a time. Each dredger had about thirty light wrought iron buckets, 12 or 15 inches long and the same breadth at the widest part, with the mouths steeled: there was an adjustment for sinking the dredger down to work to a depth of 30 feet, and the buckets delivered the sand into a moveable spout worked by a cam, which brought the spout forwards to receive the charge of each bucket as it came to the top, and then drew it back again out of the way to allow the empty bucket to pass down clear. He did not know however about the working of these machines.

Mr. Strong replied that the dredgers referred to had been used, but only to a depth of 10 or 12 feet. In shallow water they might be used advantageously, but at a greater depth the inclination was too steep for them to work well. The brick cylinders of 43 feet depth and 6 feet 9 inches inside diameter had so small space inside for the dredgers that the buckets had not room to deliver themselves in working at a great depth.

The Chairman enquired whether the layers of clay that were met with in sinking were hard enough to keep out the water.

Mr. Strong replied that the clay met with in sinking in such rivers as the Jumna was not hard like ordinary brick clay, but was nearly always mixed with sand, and consequently was not close enough to keep out water: there was also not sufficient depth of clay for the purpose. For more than half way down in the sinking, a great quantity of the sand outside the cylinders had to be taken out by the scoop, being forced up into the bottom of the cylinders by the external pressure, which rendered the progress of sinking so slow: but when down to about 30 feet depth something like fine gravel was met with, which was easier to work, although less was got out at each haul of the scoop; and this did not run in from the outside like the sand. With 35 to 40 feet head of water upon the sand it was almost as hard as stone, and there was great difficulty in forcing the scoop far enough into it to bring up a large quantity at one time: this did not however materially affect the progress of sinking. Down to a depth of 10 feet from the surface of the ground the rate of sinking was about 18 inches per day.

Mr. H. W. Harman asked what was the cost of sinking the brick cylinders by this plan, in order that there might be the means of comparing it with the cost of screw piles for foundations.

Mr. Strong said the cost of sinking each separate cylinder by this plan was 10*s*. per foot down to 5 feet depth; between 5 and 10 feet it was 20*s*. per foot, between 10 and 15 feet 30*s*. per foot, and so on, increasing regularly 10*s*. per foot at every additional 5 feet of depth, down to 40 feet depth, beyond which the rate was 90*s*. per foot. Those were the rates paid to the men for labour only, the materials being found for them. The work was all done by contract: one contractor undertook the sinking of one or more cylinders at those rates, and paid his own men.

Mr. H. W. Harman thought the cost of the sinking at that rate would be greater than by the use of screw piles. He enquired whether all the cylinders in one pier were sunk simultaneously, or whether they would interfere with one another if sunk together.

Mr. Strong replied that all the cylinders were sunk together in one pier, as it was easier and much quicker work to sink them all together.

Mr. J. Fernie asked what determined the depth to which the cylinders were to be sunk; and whether at the bottom of the deepest piers the material was still the same or was found to vary.

Mr. Strong replied that during the dry season, when the water was low, sections were taken across the rivers, and the depth of the river bed was never found to vary to any great extent, the average greatest depth at low water being about 15 feet: but the deepest part was seldom found in the same place two seasons running. The piers were generally sunk to a depth of about 43 feet below the low water level; and borings had been taken, but nothing but sand was found at a depth of 80 feet below the water level. Sometimes the sand had been found to be mixed with clay and loose stones, but nothing like rock was ever met with.

Mr. E. Gilkes enquired whether there had been any failure with the brick piers.

Mr. Strong said the only failure there had been occurred during the high floods of 1861, when the four up-stream cylinders out of the ten in one pier fell over. This was owing to the sand inside the cylinders having been scooped out in the process of sinking to as great a depth as 18 feet below the curbs, so that the cylinders were hanging as it were in their places, held up only by the friction of the sand outside. When the flood came down and the water began to eddy round the cylinders, the sand was set in motion and gradually loosened round them; and eventually, the support being taken away from them, they slipped down and in so doing quietly fell over on their sides. It was subsequently ascertained by probing with steel rods that the convex side of the cylinders was unbroken: they had simply fallen over, but had not broken to pieces.

Mr. F. J. Bramwell asked whether the fallen cylinders had been replaced yet, and whether they would not have to be removed for the purpose.

Mr. Strong said the cylinders had not been replaced when he left India last year: a cofferdam had already been made round the spot where they lay, and an excavation was being commenced for the purpose of getting down to them. When got at they would have to be broken up in order to be removed.

The CHAIRMAN enquired what sort of mortar the cylinders were built with.

Mr. STRONG replied that the mortar used in building the cylinders was the best mortar he had ever met with, and was harder to break than the bricks themselves. The lime they obtained was of excellent quality for the purpose, and pounded brick instead of sand was employed for making the mortar, and was used everywhere throughout India in preference to sand, because the sand was too fine. He had known cases where brickwork had had to be broken up by blasting with gunpowder on account of the mortar being so strong.

Mr. F. J. BRAMWELL suggested that the cylinders might be sunk much more rapidly if they were weighted with an additional load for the purpose, as there appeared to be an objection to increasing the height of the cylinders in order to get a greater weight. If they could be made to go down quicker, he thought there would not be so much sand running in from the outside, which was the cause of the delay in sinking ; and it would not be necessary to shift the scoop and windlass round several times during the day to make the cylinders go down straight. When the shaft of the Thames Tunnel on the Wapping side of the river was sunk, the brickwork was built up to a height of 25 feet on the iron curb before the excavation was commenced, in order to make it go down rapidly and steadily; and it was afterwards loaded two or three times during the sinking, to get it down.

Mr. H. W. HARMAN concurred in the desirability of loading the cylinders in order to sink them rapidly, so as to prevent the material outside from getting forced in at the bottom by the pressure of the water. He had found some difficulty with the iron cylinders of the Trent bridge that he had referred to, and had loaded them with 35 to 40 tons of railway rails: they then sank rapidly, and nothing had to be excavated except the material inside the cylinders, as none of that outside found its way in.

Mr. E. GILKES remarked that he had also found in using screw piles that when the screw came to a place where it could not be sunk further, the addition of a heavy weight on the top of the pile would make the screw bite and enable the pile to be screwed down to the required depth.

Mr. E. A. Cowper thought that not only was weighting necessary to sink the cylinders rapidly enough, but a different form of iron curb was desirable at the bottom of the cylinder, to avoid having such a large flat surface at the bottom of the cylinder, which must oppose a great resistance to its easy descent. He suggested that if the outer edge of the iron curb were prolonged considerably in advance of the bottom of the brick cylinder, so as to present a cutting edge all round, the cylinder would then sink faster, because the projecting curb would reach so far down into the sand as to prevent the external sand from getting forced up into the bottom of the cylinder. In sinking pier foundations in sand or any other loose material, rapidity of sinking was indeed essential, in order to avoid raising an unnecessarily large quantity of material. In sinking hollow piles on Potts' plan, by making a vacuum inside the pile with an air pump and so sucking up the water, gravel, mud, or other material, he had found that, when there was sufficient exhausting power and the pipe communicating from the exhausted vessel to the pile was of sufficiently large area, the pile could be got down 5 feet at a suck in certain cases; but if the suction pipe were small and the exhausting were done gradually, the outside material got sucked in at the bottom of the pile, and the sinking was slow, besides which the material about the outside of the pile was loosened. Hence it was desirable to take out the material inside the pile rapidly, so as to allow as little as possible of the external material to be drawn in at the bottom. A simple apparatus had been used by Mr. Kennard for sinking pier foundations in light soils in Spain and Italy, consisting of a rough iron box 3 or 4 feet diameter and about 2½ feet high, with an open pipe at the top about 2 feet high and 9 inches diameter, in which a cannon ball of nearly the same diameter was suspended by a chain and worked up and down by hand, forming a rough sort of pump: at the bottom of the box was another open pipe of the same diameter, standing up 4 or 5 inches inside the box and projecting about 6 or 8 inches below. This sand box was lowered down to the bottom of the water, and the ball being jerked up and down by the chain, the mixed water and sand were drawn in through the open pipe at the bottom, and the sand fell over the top of the pipe into the box, while the

water escaped through valves opening outwards in the top of the box. In this way a barrowful of sand was got into the box in a very few minutes.

The Chairman enquired whether any experiments had been made as to the resistance of the brick cylinders to sinking, and the weight required to sink them in the sand.

Mr. Strong replied that no experiments had been tried as to what weight it would take to sink the cylinders deeper in the sand after they had been sunk to their final depth; but they had tried an experiment as to the supporting power of sand under water, for some fear had been expressed at first that if the pier cylinders should ever be left partially unsupported, by the sand being scoured away from the sides, they would under the weight of the piers and superstructure sink deeper into the sand. To ascertain whether this would really be the case, the following experiment was tried. Two ⅜ inch boiler plates, 6 feet long by 3 feet wide, were rivetted together, and 20 holes to a scale of 1-100th of the actual diameter of the brick cylinders were drilled through them in the relative positions of the cylinders in two piers of the bridge. The plates were then bedded on sand, which was kept constantly wet by water standing at the same level; and the plates were weighted till there was a pressure of 18 lbs. per square inch, equivalent to 42 feet head of water, on the sand, which was then assumed to represent the actual condition of the sand under the pier cylinders when sunk 42 feet. A model to scale of one span of girders was made, resting on 10 cylinders at each end, 1⅝ inch diameter each; the ends of these cylinders were dropped through the holes in the plates, which were drilled slightly larger to let them pass freely through, so that the ends of the cylinders rested on the sand under the pressure of 18 lbs. per square inch. The girders were then loaded with weights, and it was found that with a total load of 15·7 lbs. per square inch on the cylinders they sank 3-8ths inch into the sand; and under a load of 31·4 lbs. per square inch they sank 1-16th inch deeper; but from that point up to the heaviest weight imposed of 157 lbs. per square inch they sank no further, the total sinking not exceeding 7-16ths inch, and that weight remained on for three months without the cylinders sinking any deeper. The load of

157 lbs. per square inch was equal to 10 tons per square foot: but the actual weight of the foundation, pier, and superstructure was 5650 tons on each pier; and the total area of the ten cylinders of 13½ feet diameter in each pier being 1430 square feet, the actual pressure on the foundations was not quite 4 tons per square foot. The experiment therefore proved that the piers were quite safe from sinking deeper in the sand, even under a load of more than double what they had actually to carry.

Mr. F. J. Bramwell remarked that the process of sinking the brick cylinders in the manner described in the paper might have the effect of diminishing the sustaining power of the sand, in consequence of the sand not being left dense and close round the cylinders but being disturbed by the act of sinking, the external sand getting forced up into the bottom of the cylinder, and its place being supplied by loose sand running into the vacancy left around the outside.

Mr. Strong observed that the more the sand was agitated about the cylinders the faster they would go down; and he had succeeded in sinking three piers of ten cylinders each to the depth of 43 feet in a single season of three or four months. It was only in some cases where the sand was denser that a difficulty had been found in getting the cylinders down.

Mr. E. A. Cowper remarked that the sand in the Indian rivers was constantly shifting about, so that what was in one place one season was in another place next season; and therefore it could be of little consequence to the supporting power of the sand whether it were disturbed or not in the sinking of the piers. The sustaining power of sand under compression was shown by the fact that, if a long vertical cylinder with a loose bottom were filled with sand, the pressure on the bottom would be only the weight of the cone of sand resting on the base, all the rest of the sand being supported by the friction against the sides of the cylinder, in a series of cones as it were. Sand was a very good foundation if it was not disturbed at all.

Mr. H. Woods stated that about two years ago he was engaged under the direction of Mr. J. T. Woodhouse in sinking a large well at Burton for the supply of water to Messrs. Allsopp's works; the well was 40 feet deep and 40 feet inside diameter, built in

brickwork 3 feet thick. The surface of the ground at Burton to a depth of 4 feet was generally ordinary soil, below which was a bed of gravel and sand to a depth of from 30 to 40 feet; and it was through this bed of gravel and sand that the 40 feet well was sunk. Before commencing the sinking, the ground was levelled down to an even surface at the water line of Burton, and an oak curb was laid of 40 feet inside diameter and 21 inches depth, made of a wedge form, the top side being 21 inches broad and the bottom cutting edge 3 inches broad: upon this curb the brick wall was built up to a height of 18 feet in three weeks' time, giving a weight of about 300 tons. The excavation was then commenced, the brickwork sinking as it progressed; the earth was dug out first in the middle and then round the sides close under the curb. The brick cylinder at first canted over slightly to one side, but was speedily got straight again by excavating more material from the opposite side; after which it went down all right without any further accident, and was sunk at the rate of about 1 foot per day, until it had been got down more than 12 feet. The building of the brickwork was then continued and carried on up to a total height of 32 feet, the sinking being continued at the same time; and it was found that the rate of sinking was dependent simply upon the rate of excavating, and the brickwork could be sunk as much as 18 inches per day when the excavation was done more rapidly, showing that the external friction of the ground had not much effect upon the sinking in that instance. In this way the brickwork was got down perfectly safe to the depth of 40 feet, into the position it was to occupy, and the bed of marl below was levelled to form the bottom of the well; it had sunk no further since then, notwithstanding the whole weight of the brickwork amounted to about 600 tons. The well now yielded from 500 to 600 barrels of water per hour, each barrel containing 36 gallons.

Mr. E. Gilkes enquired whether the number and size of the brick cylinders in the Jumna bridge were the result of experiment; and what was the cost of construction in that case as compared with the cost of larger cylinders, fewer in number.

Mr. Strong replied that some bridges in Bengal had brick cylinders of 18 feet diameter, three in each pier, standing on a

solid clay foundation; but the cylinders of the Jumna bridge, 13½ feet diameter, were the largest he had seen himself, and he had sunk also some of 10 and 12 feet diameter. He did not know the relative cost of the different sizes, but the objection to cylinders of large diameter was that they were more liable to crack from not sinking evenly. If the cylinder hung at all in sinking, the brickwork was liable to crack; and some of the cylinders he had been sinking cracked three or four times in going down, but the precaution adopted of building in holding up bolts prevented any injury to the work.

Mr. E. Gilkes asked whether boulders were met with frequently in sinking.

Mr. Strong said boulders were not very often met with, but when they did occur divers were sent down to excavate the sand around them and break them in pieces, so that they could be got up by the scoop. Sometimes the obstruction was a boulder, and sometimes a piece of driftwood.

Mr. E. Gilkes enquired whether the bridge was completed yet and in use.

Mr. Strong replied that it was not finished yet: the photograph exhibited showed its state fifteen months ago with the first span of the superstructure completed.

The Chairman proposed a vote of thanks to Mr. Strong for his paper, which was passed.

The following paper, communicated through Dr. A. W. Williamson of London, was then read:—

ON A
TYPE COMPOSING AND DISTRIBUTING MACHINE.

By Mr. WILLIAM H. MITCHEL, of London.

Although the process of printing from moveable types has by the power press been accelerated a hundred fold, the art of composing the types in order to be printed from has not advanced a step since Guttenberg's time. About fifty millions of letters daily are composed and distributed in the United Kingdom; and every one of these is picked from a box by the fingers, and afterwards returned to it in the same manner, without any sort of mechanical aid. Nevertheless during the last twenty years fully twenty attempts have been made by English, French, German, Danish, Italian, and American inventors to effect an economy in this direction. Three inventors have died recently, after devoting seventeen and eighteen years respectively to this subject, and have left the eventual introduction of machinery for composition still a question, and one which printers in general yet decide in the negative. In order to appreciate the efforts of these numerous inventors it is necessary to have a clear idea of the nature of the work to be performed.

The work of the compositor may be divided into five operations:—Composition, Justification, Making up, Correction, and Distribution. *Composition* consists in picking up one by one the various letters or "sorts", out of a wooden tray divided into compartments, called the "case"; and laying them together in line in the order required to form words, with small blocks or blank spaces of a uniform size between the words. As however all the lines of a page must be of the same length, and as all words do not consist of the same number of letters and all letters are not of the same thickness, the lines have to be made to correspond in length, either by dividing a word, or when that is not possible by increasing or diminishing the spaces between the words. This is called *Justification*, and in performing it

the compositor begins to measure by eye the length remaining to be filled as the composition approaches the end of the line, and the words to be put into it, and inserts accordingly either larger or smaller spaces between the words. The spaces thus inserted however must not be out of proportion to an unsightly extent with those already in; and hence it generally happens that, notwithstanding all the previous care in composing, some of the work at least has to be gone over again, the spaces already in being taken out and others put in: and the final tightening of the line in the composing stick is done altogether by trial. *Making up* is the dividing of the composed matter into pages of a given number of lines, and does not specially concern the present subject. The same remark applies to *Correction*. Lastly *Distribution* is the process by which the types, after being printed from, are returned each to its proper compartment in the case, ready to be again composed in new combinations. It consists in taking with the finger and thumb of the right hand eight or ten letters from a block of matter held in the left, reading them, and then dropping them successively into their several boxes, which operation is repeated till the whole work is distributed.

These five operations represent the work of the compositor in about the following proportions :—

Composition . . .	55	per cent.
Justification . . .	17	„
Making up . . .	7	„
Correction . . .	7	„
Distribution . . .	14	„

Of these processes, justification, making up, and correction have never been attempted by machinery. The fifth, distribution, is already very rapidly effected by hand, so that not much scope is left for saving of labour; but inasmuch as all composing machines require the letters to be primarily disposed in lines ready for setting up, it has been found necessary to use machinery to distribute them in that manner: this is however an accessory and not a principal point. There remains only composition, that is the mere setting up of the types, in which to effect an economy. To this therefore, and to the accessory process of distribution in line, inventors have directed their efforts, leaving the other processes to be done in the ordinary way.

It is of course impossible to construct self-acting machinery capable of setting up types; for the matter to be set up varies infinitely, while a machine can produce only a uniform result, the conditions remaining the same. And since a guiding intelligence is needed, the question became, on what kind of apparatus could this intelligence act most rapidly, so as to produce a series of motions simple in themselves, but occurring in a perpetually varying series? The obvious answer was "finger keys," and accordingly all composing machines have been constructed with finger keys. But here a difficulty presents itself. The number of sorts or characters, for each of which a type reservoir and key must be provided, ranges from a minimum of forty to a maximum of more than two hundred. The space required therefore makes it necessary to place some at least of these type reservoirs at a considerable distance from the point at which the letters must meet to form words. Over this distance the types cannot be carried directly by the action of the key, without giving the latter so much to do as to make the fingering stiff and awkward. A secondary means of conveyance from the separate type reservoirs to the common receiver has therefore to be provided: which must be so arranged that the letters from whatever distance will arrive at their destination in the same order in which the keys are touched. As this is the main requirement, the manner of attaining it generally prescribes the character of the details, and may be taken as the distinctive feature of the different inventions for the purpose.

The different constructions of composing machines may be divided into two classes:—those in which each letter is by a rapid motion carried to its destination before the next letter is liberated; and those in which several letters may at the same time be travelling by different routes towards the point of setting up, the means of transit being so arranged with regard to time or distance that the letters shall arrive at their destination in their proper order. To the first class belong Beaumont's and Loughborough's machines, in which the carrying is performed by an arm rotating rapidly in a horizontal plane, the type reservoirs and the receiving line both forming produced radii of the circle described by it, and the action of the key being to bring the type within the sweep of the arm. The second class comprises the machines

of Sörensen, Rosenberg, Young, Hattersley, and Alden, together with that forming the subject of the present paper.

In the composing machine of M. Sörensen, a Danish inventor, which attracted much notice at the Paris Exhibition of 1855, the type reservoirs were placed round the edge of an inverted hollow cone, over the inner surface of which the types slid down, and through the apex of the cone to the receiver. This brought all the different sorts within an equal distance of the receiver. On the top was placed a self-acting distributing apparatus to supply the reservoirs with type.

In Rosenberg's machine the type reservoirs were arranged as vertical lines in a row facing and parallel to the keyboard; underneath them was an endless band traversing rapidly from right to left, which carried the letters as they were dropped upon it to the receiver placed at the left of the machine. The drawback to this arrangement consisted in the fact that when a letter near the left had to follow after one coming from the right, time had to be allowed for the first letter to pass to the left before the second key could be depressed; a drawback however which was thought to be counterbalanced by the advantage that, when the letters occurred in a series which extended towards the right along the keyboard, several keys might be depressed simultaneously.

In Young's machine the means of transit from the type reservoirs to the receiver consist of a plate in the form of an equilateral triangle, inclined towards one of its angles, and furrowed by a system of curved grooves converging towards the lowest angle, the type reservoirs being ranged along the opposite or highest side of the triangle. Through these grooves the letters descend by their own weight, and the mode of convergence of the grooves is such that, although the type reservoirs cannot all be at the same distance from the receiver, the length of their route thither is nearly the same; and the time of transit of the letters may therefore be presumed to be the same. A self-acting distributor is also employed, which however works independently of the composing machine.

In Hattersley's machine there are points of resemblance to the preceding, inasmuch as this also causes the letters to descend through a triangular system of converging grooves to the receiver. But a very condensed arrangement of the key action and type reservoirs is adopted

in this machine, whereby the distances are made less, and accordingly the triangular guide plate is much smaller, being in a vertical plane, instead of inclined like that in the preceding machine. The delivery by this machine is almost instantaneous, so that each letter almost reaches the receiver before the next letter begins to move. The machine has also the advantage that the line in course of composition is directly under the eye of the compositor. Mechanical distribution is here discarded altogether, the types being distributed in the ordinary way and afterwards arranged by children in the required manner for the composing machine.

The combined composing and distributing machine invented by Mr. Alden of New York is altogether peculiar, and is perhaps the most complex and comprehensive machine yet constructed for the purpose. In the centre is a slowly rotating horizontal wheel, around which, as produced radii, are placed reservoirs for more than two hundred sorts of types. On the circumference of this wheel are fixed sixteen moveable boxes, serving the purpose of hands to take up and deliver the types, eight being for composition and eight for distribution. The matter for distribution is placed at the right side of the machine, and each distributing box as it passes takes away a type, and guided by the position of the nicks cut in it deposits it in its proper reservoir. At the other side of the machine are the finger keys, whose action by an indirect and intricate process sets the mechanism of each composing box as it passes in the position to seize a particular letter, also indicated by its nicks, and carry it to the receiver; so that precisely the same number of letters is distributed and composed, and thus a page of printed matter is distributed line from line and letter from letter, and the letters are recomposed, without once being handled by the compositor.

The Composing Machine now exhibited combines Rosenberg's method of carrying the letters by endless bands, with Young's idea of so arranging their route that all will take an equal time to reach the receiver.

The general arrangement of the composing machine is in a horizontal plane, and in shape it resembles a triangular table, as shown in the plan, Fig. 1, Plate 6. The table is traversed by a series

of parallel endless bands A, the return side of the bands passing underneath. These bands are all made to travel with an equal and uniform velocity in the direction of the arrows by passing round the shaft B driven by the steam engine. Obliquely to these and at a somewhat lower level a collecting band C skirts the machine diagonally, deriving its motion indirectly by a round driving cord from the same driving shaft B. Above the bands A stands a row of the type reservoirs or slides D, one band passing under each reservoir. The keyboard E extends along the front of the machine, each key communicating with the type reservoir directly in front of it. The sectional view, Fig. 3, shows the framing, the respective levels of the bands A and C, a section of the bed plate F which supports the type reservoirs D, and the position of the keyboard E. When the types are liberated from their respective reservoirs by the action of the keys, they drop on the parallel bands A, which deliver them on to the diagonal collecting band C, and this in turn carries them to the receiver or setting-up wheel at G.

The parallel bands A, Fig. 1, Plate 6, travel at the rate of about six inches per second, and the diagonal collecting band C at fifteen inches per second. The object of this peculiar arrangement of the bands is that all the letters may take an equal time for their transit from the reservoirs D to the receiver G. Although there are forty reservoirs D and no two are at the same distance from the receiver G, an equal time of travel for each type is obtained by the use of these two velocities only. The route of each letter is made up of two parts, one on the slow band A and the other on the fast band C; and the proportion of these parts varies with the whole distance, so as to give in every case a mean velocity proportionate to that distance, so that the actual total time of passage is the same for each type. Thus in the diagram Fig. 2, Plate 6, if A D be the line of reservoirs; D G, T R, and S F, bands of the parallel series; A G the diagonal quicker moving band, and G the receiver: then S has further to travel than T in order to reach G. But T has the part T R slow and only the part R G fast, whereas S has only the part S F slow and the part F G fast. In order to find the necessary proportion of speed, suppose D and S to start together; then as they are carried on bands of equal velocity they will arrive simultaneously at E and F, when one will still have

to travel over E G and the other over F G; in order therefore that they may complete their journey together, it is only necessary that the velocities along E G and F G should be as their lengths. And the same proportion applies to all the cases, the several triangles being all similar. Since therefore all the letters take an equal time to reach the receiver G, any two starting together will of course arrive also together, and any two starting in succession will arrive one after the other in the same succession; and hence any number of letters may be played out in any series from the type reservoirs D, Fig. 1, with the certainty that they will arrive in the same series and with the same intervals between them as at starting. In the hands of a swift operator before the first letter of a sentence has reached its destination twenty or thirty more are already on their way; and although they seem to be in confusion while on the parallel bands A, they resolve themselves into a string as they fall upon the diagonal collecting band C, with intervals of about 1½ inch between each of the types.

Following the course of a type in its transit from the type reservoir to the line in which it is composed, Fig. 4, Plate 7, is an elevation, and Fig. 5 a plan, drawn half full size, of a type reservoir D, with the key and key action E, and the endless band A passing underneath. Fig. 6, Plate 8, is a back end view, drawn full size, of three type reservoirs D, and the key action. The type reservoir D is a channel or slide of sheet metal inclined at an angle of about 55 degrees, Fig. 6. It is made with an eye at the back to fit on a pin in the bed piece H cast in type metal. These bed pieces are made to fit into the grooved bed plate F, Fig. 4, and overlap one another so as to hold in a recess the small steel stop plate I, shown black in Fig. 6, which serves as the stop for the types in the reservoir D; and the whole of the parts are put together without the use of screws. When the types are brought up by the stop I, as shown at the first slide R in Fig. 6, the lowest has already passed out of the slide D, but is prevented by friction from falling out. The key E, Figs. 4 and 5, is attached to a rocking shaft J fitted in bearings at each end, and carrying at the end next the type slide an arm K, on which is a small shank parallel with the rocking shaft J. On this shank is placed the striker L, which is formed as a tube fitting freely on the shank, and

having flanges projecting from it on each side of the stop I to take the type. The striker is brought up against a stop on the rocking-shaft arm by a light india-rubber spring M. When the key E is depressed, a partial rotary and downward movement is given to the arm K, and the striker L descending takes the type at each end, as shown at the centre slide S in Fig. 6, and forces it downwards until it is clear of the stop I, when the type falls upon the endless band A below. The types in the reservoir, overcoming by their weight the resistance of the india-rubber spring M that holds up the striker L, descend at once upon the stop I, forcing the striker backward, as shown at the third slide T in Fig. 6. The key being now released, the striker rises and recovers its former position by means of the india-rubber spring M. The descent of the key is regulated by a screw underneath, and its ascent by the T headed screw N passing through it, Figs. 4 and 5. Under the key is a very weak conical spring O to raise it when the finger is lifted. One of the advantages of the yielding striker L just described is that this spring O under the key can thus be much weaker, not having to overcome so much resistance in raising the key: this is a point of great importance as regards rapidity of fingering.

The types thus liberated from the type reservoirs are immediately carried on towards the diagonal collecting band C, on which they are delivered by a sort of curved spout, as seen in the plan, Fig. 7, Plate 8, where the types are represented in about the respective positions they would occupy if played out in the succession indicated by the numbers. The types are turned into their new direction by the motion of the bands themselves: it was a point of some difficulty to find a means of transferring them from one band to the other at a high speed without turning them over, and the difficulty was greater with small sizes of type.

The diagonal collecting band C carries the types to the receiver, where they are set up in long lines by a kind of ratchet wheel G, Fig. 8, Plate 9, formed of successive thin steel plates with discs of sheet metal between, as shown full size in Fig. 9, resembling a number of circular saws revolving backwards. On the circumference of this wheel at a point nearly over the centre the types are delivered

by means of a small shoot, and slipping into the ratchets are carried round into a vertical position, when they are caught by small steel fingers placed in the interstices between the steel plates of the ratchet wheel, as shown dotted at P in Fig. 8; the following ratchet teeth then acting as cams push the types along as part of the line composed. The shoot and wheel G are tilted slightly, as shown in Fig. 9, causing the types to hug the lower side; and the wheel has one plate of larger diameter on that side, serving as a fence to prevent the types from falling off. The other side of both wheel and shoot is left open, so that if two keys should be touched at the same time or any other accident should cause two letters to arrive together at the setting-up wheel, one is thrown off and no choking takes place, the type thrown off being caught in a tray fixed below.

The lines of type composed in this manner pass out upon a long moveable rod, which when full is emptied on a kind of desk with ledges, where it is justified. This is done in the ordinary way, except that the lines are lifted into the compositor's "stick" with one hand, by means of a grab of sheet metal, slightly curved, having one end hooked and a lug at the other end. The lug being laid hold of by the forefinger and a slight pressure exerted by the thumb upon the end of the line of type, the latter forms itself into an arch in the grab, and may then be lifted without risk of falling to pieces. This is done very rapidly with a little practice. The types once in the composing stick, which is of the usual pattern, the remaining parts of the process, justification, making up, and correction, are performed by the compositor in the ordinary manner.

This new method of composition makes it necessary to adopt a new plan also for storing the type, the old cases being no longer of any use for that purpose. For the composing machines the letters must always and under all circumstances be kept arranged in line. When in store therefore they are placed on thin wooden slats 13 inches long, so formed that a number of them charged with type may be laid together or lifted together. These slats are placed on racks under the composing machine, and in feeding the machine the lines of letter are slipped sideways off the slats into the type reservoirs D of the machine, Figs. 4 and 5, Plate 7.

This composing machine is capable of setting up types at the rate of 6 letters per second or 21,600 per hour; but as the compositor's fingers cannot attain to such rapidity, and allowance has to be made for the operations of justifying and correcting, the work of an average trained compositor will probably not exceed 24,000 or 25,000 letters per day, which is about equal to the work of two men setting up type by hand in the ordinary mode. Each composing machine can employ two men, making the daily production about 50,000 letters with one machine.

When the composed matter has returned from the press, all that remains is to distribute the various types into separate receptacles and replace them on the store slats, so that they may be used again in the composing machine. The first step is to place several lines of a page end to end, so as to form a single long line of letters, in which form they are fed into the self-acting Distributing Machine, the general arrangement of which is shown in the plan, Fig. 10, Plate 10, drawn half full size. The long line of letters is placed in a horizontal feed channel A, in which they are drawn forwards, as successively distributed, by the follower B with a string and weight attached, moving in the direction of the arrow. At the mouth of the feed channel they are cut off singly by the vibrating striker C, and fall into grooves cut in the circumference of the conical distributing wheel D, which revolves horizontally at a slow speed beneath. The distributing wheel D revolves above a stationary base E, also conical, the two forming together a frustum of a cone, as shown in Fig. 17, Plate 11. At the lower end of each of the sixty grooves in the circumference of the distributing wheel is a small pin F, Figs. 17, 18, and 19, on which the types as they fall through the grooves become suspended by means of nicks cut in their sides, but not until their lower ends have passed a short distance out of the grooves, so that the foot of the type projects over the surface of the stationary base E. As the nicks are cut in different positions in the different letters, some types project further from the grooves than others, and so descend further over the surface of the conical base E, as seen in the diagram Fig. 21, Plate 12, which represents an elevation of a portion of the circumference of the

distributing wheel D and base E, projected all in one plane for the sake of illustration. On the base E is fixed a series of offsets G, each presenting a horizontal incline to the lower ends of the types, as these are carried round by the distributing wheel; and when the foot of a type comes in contact with one of the offsets it is canted outwards by the incline, until the nick by which the letter hangs becomes clear of the suspending pin F, when the type drops into one of a series of radial receiving lines H in the stationary base E, and is immediately pushed forwards along the line to make room for others, as shown in Fig. 17, Plate 11.

The offsets G, Fig. 21, Plate 12, are arranged in a series of steps ascending in the direction of the distributing wheel's motion, each being fixed a little higher up on the base E and therefore nearer the wheel D than the one behind it. Consequently those letters which project the furthest below the grooves of the distributing wheel are first brushed off, and the rest follow in due succession. As all the letters are thus removed in the course of one revolution of the wheel, the grooves return empty under the feed channel A, Fig. 14, Plate 11, to be again filled; and so the distributing wheel goes on filling, emptying, and refilling itself, till the line of letters to be distributed is exhausted. The receiving lines H, Figs. 17 and 21, placed under the several offsets G, extend outwards radially, as shown in the plan, Fig. 10, and are 13 inches long, each having a small loose sliding block, Fig. 17, to keep the types upright in the line. As each line fills up with its appropriate letter, the contents are slid out by the attendant on to a brass rod, dumped on the store slats, and placed on the racks under the composing machine, ready for use again in composing.

The first difficulty in the distributing machine was to find a means of cutting off the letters one at a time from the feed line A, Fig. 10, Plate 10, as they often adhere strongly together with printing ink, and are moreover of many different thicknesses, some being five times thicker than others. This is effected by the following contrivance. The feed line A when drawn forwards in its channel is brought up at the end of the channel by an inclined stop I, Figs. 11 to 16, Plate 11, formed of a small steel plate, shown black in Figs. 11 to 13, projecting

a short distance across the mouth of the channel A, and placed at an angle of 45 degrees to its bed. When a thin letter is foremost, as in Fig. 11, the advance of the line is arrested by the upper edge of the stop plate I, which is sufficiently far in advance of the channel mouth to permit all types under a certain thickness to clear the channel. But in all types above this thickness, a nick is cut in the side of the type, into which the upper edge of the stop plate I passes, as in Figs. 12, 13, and 14 ; and the advance of the line is then checked, not by the upper edge of the stop plate, but by the lower side of the nick coming in contact with the under sloping face of the plate I. The point at which the type is arrested depends of course upon the distance the nick extends downwards in the type, and this distance is always made proportionate to the thickness of the letter, as illustrated by the types shown full size in Figs. 22 to 25, Plate 12; the nick Q is widest in the thickest type, Fig. 22, and not so wide in the thinner type, Fig. 23, while the thinnest type is devoid of the nick altogether, Figs. 24 and 25. In this manner every letter of whatever thickness is permitted to pass out just clear of the feed channel mouth; and is then cut off by the vibratory motion of the striker C, Figs. 15 and 16, without danger of carrying another letter with it.

The plans, Fig. 10, Plate 10, and Figs. 15 and 16, Plate 11, show the arrangement of the parts for cutting off the letters from the feed line A in the distributor. The striker C is a lever vibrating horizontally on a vertical centre and receiving its vibratory motion from the cam J on the vertical driving shaft of the machine. On the same shaft is a second retarding cam, which presses against the forked break lever K, Fig. 16, serving to retard the advance of the line of letters and prevent a sudden blow of the foremost letter against the stop plate I. The return motion of the striker is effected by a spring bearing against a second spring L, which when pressed upon by the first spring bears against the leading letters of the line A, as in Fig. 16, and holds them steady while the first letter is cut off for distribution, preventing the next letter from being pushed forwards against the end of the striker C. During the first 90 degrees of revolution of the vertical driving shaft J, the retarding cam and break lever K allow the line of letters to advance until the foremost letter is

brought up by the stop I; the break lever K then remains pressed against the front letter of the line by a weak spiral spring. In the next 30 degrees of revolution the striker cam J acting against the roller upon the striker C cuts off the foremost letter from the line; and during the next 30 degrees of revolution the striker is held by the cam J in this position, as shown in Fig. 16, Plate 11, so as to give the letter time to drop through the shoot M into the distributing wheel below; in another 30 degrees the striker returns to its original position shown in Fig. 15, the driving shaft J having then accomplished half a revolution. The other half revolution is similar; so that each turn of the driving shaft cuts off two letters, and the driving shaft being geared to the central spur wheel N so as to make thirty revolutions for one of the central wheel, one letter drops into each of the sixty grooves of the distributing wheel D as it passes beneath the striker C. The shoot M, Figs. 13 and 14, Plate 11, conveying the types into the grooves of the distributing wheel, has a guide on one side only, to guide the types into the grooves of the wheel, since the latter moves in the direction of the arrow, Fig. 14; and the grooves have tapered openings with the same view.

The diagram Fig. 21, Plate 12, represents the distributing wheel D charged with types, moving in the direction of the arrow; also the stepped series of offsets G on the base E, and the radial receiving lines H. Fig. 18, Plate 11, is a section of the circumference of the distributing wheel D through one of the grooves, showing the manner in which the types are suspended on the pins F. Fig. 19 is an end view of a groove and type, enlarged to double full size, showing how the type descends through the groove, tilted up with one side resting on the pin F, until a nick occurs in that side, when it drops on the pin and becomes suspended. Fig. 17 exhibits a section and profile of the distributing wheel D and base E, showing how the type, lifted from the pin by the offset G, falls into its receiving line H, and is there pushed forwards by the driver O worked from within the base.

Referring now to the left side of Fig. 21, Plate 12, the type No. 1 is there shown as just dropping into its groove in the circumference

of the distributing wheel from the feed channel A of the machine. It is received upon the plate of steel P, attached to a projection of the base E and occupying the small space between the suspending pins and the bottom of the grooves in the distributing wheel D. Carried along by the motion of the wheel, the foot of the type encounters an offset on the steel plate P, presenting a horizontal incline, which pushes its foot outwards far enough to enable it to pass over the plate P and suspending pin, when its fall downward is arrested as at type No. 3 by the edge of the inclined plate R screwed to the surface of the base E; and following the descending incline of the plate R as at Nos. 4 and 6, and with one side resting on the pin F, Fig. 19, Plate 11, the type gradually descends until the nick cut in its side reaches the pin, when it slips on to the pin and thereby becomes suspended, and is so carried forwards, like Nos. 5, 7, 8, 9, and 10. These types it will be observed hang at different heights, and are thus fitted to come in contact with different offsets of the ascending series G. Nos. 11 and 12, having already come in contact with their appropriate offsets, and having been by them lifted off their pins, are represented dropping between the guides into their receiving lines H.

There are only ten offsets in the first stepped series G, Fig. 21, Plate 12, and therefore only ten letters can be distributed by them: but to the right of the diagram is shown a second descending incline R, and the commencement of a second series of stepped offsets G and receiving lines H like the first. There are four of these series succeeding one another round the base E of the distributor, and the manner of using them is as follows. Since there are forty sorts of type to be distributed, and each requires to differ from its neighbour by 1-32nd inch in the position of its distributing nick Y, Figs. 22 to 25, and as only 3-8ths inch of the type's length is available for these nicks, it becomes necessary to use the same nick for several letters. This is done by combining with it a second nick Z, Figs. 23 to 25, placed nearer the foot of the type; so that the type, becoming suspended by this lower nick first, is held above the reach of any of the first series of offsets, and reserved for the second, third, or fourth similar series. Thus the types Nos. 13, 14, and 15, in the diagram Fig. 21, Plate 12, have one nick, the upper one, similarly placed to that in the type No. 12;

but having in addition a nick nearer the foot, their fall has been arrested by this lower nick, and so they have been carried past the place where No. 12 dropped off. When the type No. 15 arrives at the commencement of the class or series to which it belongs, its foot meets with an offset similar to the others, but having a projection below ; so that the type, though lifted off its pin, is not permitted to drop ; but descending the second incline R similar to the previous one, as at Nos. 16 and 17, it will then become suspended by the upper nick, and will afterwards be finally lifted off the suspending pin and distributed by the corresponding offset of the second series. In like manner the types Nos. 14 and 13, having nicks successively still nearer the foot, will be carried respectively past the second and third divisions and distributed in the third and fourth divisions. The nick Z near the foot, Figs. 23 to 25, which determines the series or class that a letter belongs to, is called the *class* nick ; and the upper nick Y which determines the particular receiving line it shall fall into is called the *sort* nick. Since therefore the four series of offsets are all similar, each class nick Z appears in ten different letters, and each sort nick Y in four different letters. If a letter belong to the first series, it has the sort nick Y only, as in Fig. 22, and is at once suspended by this nick and distributed; but if it belong to the second, third, or fourth series, it has the class nick Z also, as in Figs. 23 to 25, sufficiently near its foot to carry it clear of all the offsets till it reaches its own division, when it descends to its sort nick Y and is distributed. All the ten letters of the same class therefore have one nick, the class nick Z, in common ; and also sort nicks Y, differing from one another in the same class, but corresponding to the sort nicks of the other classes. In this manner the distributing machine divides the letters just as a naturalist divides his specimens into genera and species ; all the members of a class or genus having one feature in common, which serves to distinguish them from the members of the other classes ; while each particular type again has a feature peculiar to itself, which serves to distinguish it from the rest in the same class.

The plan, Fig. 20, Plate 11, shows the manner in which the drivers O are worked for pushing the types along in the receiving lines H, Fig. 10. The loose ring S on the centre spindle of the

distributing wheel receives an oscillating motion from the connecting rod and crank J on the main vertical driving shaft of the machine, and has the four series of drivers O jointed round its circumference. With every oscillation of the ring S, the drivers O advance and recede, the machine being geared together so that their advance coincides in point of time with the passage of the distributing wheel grooves above the receiving lines H, so that they advance and retire once for each groove in the wheel. On the same vertical driving shaft J is placed the cam giving motion to the striker C at the mouth of the feed channel, Fig. 10, whereby the movement of the striker also coincides with the passage of the distributing grooves below, as already described.

In order to prevent any injury being occasioned by accidental sticking of any of the types in the grooves of the distributing wheel, a stop action is provided for stopping the motion of the machine immediately, which prevents the wheel from damaging the type or receiving any injury itself. For this purpose the distributing wheel D, Fig. 10, Plate 10, is carried round by the motion of the spur wheel N by means of the spiral spring T: on the distributing wheel is fixed a projecting stud, contiguous to a cranked finger U centred on one of the arms of the spur wheel N. In the regular working of the machine this finger runs round loose on the circular plate V below, which forms one end of a stop lever connected with a catch W that stops the main driving pulley X of the machine. But in the event of any accident whereby the distributing wheel D is held back, the finger U is brought up against the stud on the distributing wheel and is thus depressed, thereby depressing the stop lever V and bringing the catch W against one of the stop pins on the driving pulley X. The motion of the machine is thus stopped instantly, until the obstruction has been removed by the attendant, when the catch W is released by a balance weight and the working is resumed as before.

The distributing machine requires only the attention of a boy, and distributes 8000 letters per hour.

The nicks in the types required for the distributing machine are cut in them by means of a plane with three cutter heads, admitting of all the nicks being cut at once. The adjustments for giving the nicks

their proper positions are simple and easy, and either new or old types are nicked, usually at a cost of one penny per lb.

The number of characters provided for in the composing and distributing machines now described is limited to about forty. This seems at first a serious defect, inasmuch as the number of characters required even for plain work, counting roman capitals, small capitals, italics, and numerals, amounts to about two hundred. The small number of forty was adopted however from calculation and not from necessity; for the distributing machine is susceptible of considerable extension, and the composing machine of any desirable extension. But in any work otherwise adapted to the machines, the 160 excluded sorts really amount to only from 2 to 5 per cent. of the entire matter; and in consideration of the necessarily complicated character of the mechanism, and the moderate saving to be hoped for at the best, it was thought better to dispense with an extension which would double the cost of the machines while adding but 5 per cent. at most to their efficiency. The extra sorts are therefore placed in a case in the composing machine, and are dropped by hand into a shoot as they occur, passing along on the endless bands with the other types to the setting-up wheel: while in the distributing machine these extra sorts, having no suspending nicks in them, drop off the distributing wheel at the commencement into a separate receptacle, and are then distributed by hand. The composing machine is usually constructed to work three different sizes of type without adjustment; and the distributing machine is capable of adjustment, with a change of the distributing wheel for each size of type.

The economic bearing of these composing and distributing machines, and the results actually obtained in work done where they have already come into use, remain now to be considered. Of the numerous inventions for the same purpose that have been brought forwards at intervals within the last twenty years, some were the subject of much attention; and several were for a time at work, more or less experimentally, but afterwards fell into disuse. And in the case of the machines now exhibited, their progress during the nine years

they have been in existence must be regarded as extremely slow. It might have been expected, from the undoubted advantage possessed by finger keys over the hand picking-up process, that a saving would be effected large enough at once to overbear all objection, and lead to the speedy and general introduction of the machines. But this is not the case. The saving has never exceeded 50 per cent., diminishing under less favourable circumstances to little or nothing; while the difficulty of adapting the new method of composition to the present conditions of printing has been very great. That the saving falls short of what might be anticipated is owing to the circumstance that the work of the compositor consists as already stated of several distinct operations, some of them susceptible of mechanical aid, but others either not susceptible or hitherto unattempted. What makes the difficulty greater is that it is not easy to separate one operation from another. For instance it is inconvenient to charge one compositor with the justification or correction of work composed by another: consequently it is impossible to introduce that division of labour indispensable for obtaining the full benefit of machinery. The compositor has thus to pass from an operation in which he is assisted by mechanism to others which are purely manual; and one result of this shifting about is that the machine stands idle about one fourth of each day. A still more serious result is the waste of time inevitable wherever there is frequent changing from one process to another. The mere setting of the types in line, in which alone a saving is effected, amounts as has been stated to about 55 per cent. of the whole work; but even this includes the operation of reading the copy, which cannot be accelerated by machinery: so that the actual fingering of the keys is reduced to about 50 per cent. of the gross work. Supposing therefore that the compositor is enabled by the keys to set up seven letters for one that he could set up by hand, there results only a saving of about 43 per cent. on the whole process.

Another difficulty arises from the extremely irregular and fluctuating supply of work of any given character in printing establishments. Unlike other extensive trades there is in this but little classification. Every printing office undertakes every description of work, from a card to a book. But composing machines are not

suited for doing cards, nor for what is called "displayed work", nor in fact for anything but tolerably plain straightforward work; so that frequent variations in the character of the supply are for machines very inconvenient. If these machines could, like the power loom, be kept regularly supplied with suitable work, their success would be assured notwithstanding all drawbacks. A printer possessing sufficient capital, making mechanical composition the basis of his operations, and accepting only such other work as might be a necessary accompaniment of that, would undoubtedly in the first instance encounter difficulty in drawing business out of its accustomed channels, but would in the end be enabled to underbid competitors adhering to the old method. So long however as the present system prevails of doing all descriptions of work in one establishment, hand labour from its versatility certainly possesses an advantage as compared with any machinery.

As to what has been effected hitherto in actual work, it is sufficient to say that a pair of these machines introduced into an establishment in New York about nine years ago are still in use, together with several others afterwards purchased. Five years after their introduction, the proprietor of that establishment made the following comparative statement regarding one work, a Bible, set in english size type, which he had just completed. The 1086 pages of the work were composed on two composing machines, and the distribution was done on two distributing machines. The entire work measured 6½ millions of letters, and was set up in sixty days with 1000 lbs. of type by three apprentices and one journeyman, and the distribution was done by two boys. The cost was as follows:—

	£.
769 pages set up by three apprentices at two thirds price, about .	38
317 " " one journeyman	24
Two boys for distribution, and one for other purposes . . .	13
Total	£75

The same work done by hand composition, but without regard to time, would cost:—

	£.
769 pages set up by three apprentices at two thirds price, about .	86
317 " " one journeyman	53
Total	£139

The cost of the machine work was thus only 54 per cent. of hand setting: but to do the same work by hand composition in the same time of only sixty days would require at least ten journeymen and 2000 lbs. of type.

About two years ago a pair of these machines was placed on trial in the printing office of Messrs. Spottiswoode and Co., London, and the result of a month's performance was 500 hours of small pica reprint produced in 196 working hours. On this occasion the work was done by a compositor from the New York office. Three machines were thereupon adopted by this firm, and several others by printers in London, Bungay, Glasgow, and Oxford. Although it cannot be pretended that in any of these establishments a result so favourable as the above has as yet been attained, still careful calculations show a margin of profit, small indeed at present, but increasing, and reasonably expected to go on increasing as the operators acquire skill and difficulties and opposition of many kinds are smoothed away. Moreover a collateral advantage appears in a diminution in the wear and tear of the type, and a diminution in the quantity of type required to produce a given amount of work.

The whole advantage of the machines may therefore be summed up as follows. First, a saving of about 43 per cent. in the labour of composition, under favourable though not exceptional circumstances. Secondly, a diminution of about 20 per cent. in the wear of type. Thirdly, a diminution of about 30 per cent. in the quantity of type required for a given amount of work.

In conclusion it deserves to be mentioned that, although their progress has been very slow, in no case have these machines when once introduced afterwards fallen into disuse. It seems probable that ground so slowly won will not be lost, and that a portion at least of the great work of composition will hereafter be accomplished with the aid of machinery.

Mr. Mitchel exhibited the composing and distributing machines and showed their action, and also the planing tool for nicking the type for the distributing machine.

Mr. J. Jaffray was greatly interested in the subject of the paper just read, which he thought had been treated with great fairness, showing clearly the real difficulties that had to be encountered in applying machinery to the composition and distribution of type. There would be a very large field for the use of machinery for the purpose, if it could be adapted for the work of newspaper offices, where rapidity and economy in composing were of so much importance; but the usefulness of the machines in this case would be very much determined by the size of type that could be composed and distributed by them, and he enquired what was the smallest size of type on which they had been employed.

Mr. Mitchel replied that the composing machine was not limited as to the size of type that it was capable of setting up; the smallest size of type that it had actually composed at present was nonpareil, and it had composed every size from nonpareil up to great primer.

Mr. J. Jaffray observed that in the distributing machine, where the distribution was effected by means of nicks cut in the body of the type, the size of type that could be distributed would be limited by the strength of the type when nicked, which he thought would prevent the distributing machine from being employed for the smaller sizes of type. Even the present single shallow nick that was ordinarily made in the edge of the type rendered the hard metal types now used very liable to break at the part nicked, especially in using the American Hoe printing machines, in which there was some liability of injury to the type in levelling it down upon the press: and in proportion to the smallness of the type would be the weakness caused by the nick. For newspaper work therefore he feared the composing and distributing machines could not be introduced with advantage, first on account of the great number of different sorts of type that occurred in that class of work, such as italics, figures, short lines, and capitals, &c.; and secondly because at the present time a very large quantity of type had to be used of sizes smaller than nonpareil, such as ruby, to which the

distributing machine could not be adapted on account of the nicks weakening the body of the type so much.

Mr. MITCHEL explained that it was not proposed to use the machines for displayed work, such as advertisements, where different sorts of type were used in the same piece of work; but simply for plain straightforward work, such as ordinary book work, not dictionaries or time tables. The machines were also suitable for the editorial and news departments of newspapers; but they had not at present been tried on newspapers at all.

Mr. C. W. SIEMENS observed that both the machines exhibited involved a great many nice mechanical operations and displayed a great deal of ingenuity. The mode of distributing the type by classifying the different letters by means of notches was a highly ingenious arrangement; as also the method of conveying the types in the composing machine by means of the two sets of bands running at proportionately different speeds, whereby the types were set up in the same order in which they were played out by the finger keys. In the case however of two keys being accidentally pressed down at the same instant, two types would arrive together at the composing wheel and one of them would be thrown out, causing a fault in the setting up; but this he suggested might be easily prevented by fixing a tape band extending under all the keys, about ½ inch longer than the actual length of the keyboard, so as to have only sufficient amount of slack to allow one key to be depressed at a time. That was the plan adopted in telegraph instruments worked with finger keys, to prevent more than one key being pressed down at once; and he thought some simple contrivance of that sort could be advantageously adopted in the composing machine.

Mr. F. J. BRAMWELL enquired what became of the exceptional types, when a quantity of matter was placed in the distributing machine for distribution, since it appeared the machine was adapted for distributing only 40 different letters, whilst there were in all about 200 different sorts in the ordinary run of matter that would have to be distributed.

Mr. MITCHEL explained that the remaining 160 different letters would be deposited by the distributing machine in the first receptacle,

and would not be carried round by the distributing wheel, as they did not contain the nicks required for distribution by the machine; and they would then be readily distributed by hand, their proportionate number being only very small.

The Chairman enquired how many of the machines there were at present in use.

Mr. Mitchel replied that taking composing and distributing machines together there were in New York fifteen of the machines which had been at work more than three years; and in three establishments in London there were seven machines, in Oxford one, in Bungay three, and in Glasgow two.

The Chairman enquired whether there were as many distributors as composing machines; and he asked what was the cost of the machines.

Mr. Mitchel said there were not as many distributors as composing machines, but in some places there were two or three composing machines to only one distributor; and the composing machines might be worked alone without the distributor, the distribution being then done by hand, in which case no nicks would be needed in the type for distribution. The cost of the machines was about £60 for each machine.

The Chairman proposed a vote of thanks to Mr. Mitchel, for his paper and the machines exhibited, which was passed.

The Meeting then terminated; and in the evening a number of the Members dined together in celebration of the Sixteenth Anniversary of the Institution.

PROCEEDINGS.

7 May, 1863.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 7th May, 1863; Sampson Lloyd, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman had much pleasure in announcing that a donation of £50 had been received from the President, marking his sense of the value of the Institution and the interest he felt in its welfare and advancement. He regretted that the President was prevented by illness from being present to take the chair at the Meeting, as he hoped to have done.

The thanks of the Meeting were voted to the President for his handsome donation.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Edward Barlow, . . .	Bolton.
William Steel Brown, . .	Glasgow.
George Crow, ...	Newcastle-on-Tyne.
John Pitt Kennedy, . .	London.
John Lancaster, ...	Wigan.
Samuel Lees, Jun., . .	Ashton-under-Lyne.
Matthew Hill Loam, . . .	Nottingham.

William Ryder, ...	Bolton.
Wallace Cochrane Somerville, .	Westbromwich.
John Henry Storey, . . .	Manchester.
John Wakefield, ...	Dublin.
Joseph Whitley, ...	Birmingham.
Tom Whittaker, ...	Nottingham.

The following paper was then read:—

ON THE CONSTRUCTION OF DRAWING ROLLERS FOR SPINNING MACHINERY.

By Mr. WILLIAM WEILD, of Manchester.

The process of laying fibres of cotton, wool, and flax in parallel and continuous juxtaposition, for the purpose of being spun into threads for various manufactures, was performed until little more than a century ago by the workman's fingers, assisted sometimes by a preliminary operation of carding, which formed the short fibres into a soft fleecy roll of about ¾ inch diameter and 10 or 12 inches length according to the size of the card used. The spinning was done by the distaff, a wooden rod, round the top of which a bundle or fleece of the fibre intended to be spun was loosely wrapped. The spinner holds the distaff in the left hand, and the right hand is held about two inches below it, more or less according to the length of the fibre. A continuous lock of fibres is drawn out from the fleece on the distaff by the right hand, and the length between the two hands is twisted into a fine thread by the hanging spindle or bobbin, which is kept constantly revolving by the impulse of the fingers. The thread spun is wound up at intervals on the spindle by stopping the operation of twisting, and winding on to the spindle the length of thread already twisted: and to prevent the spun thread unwinding from the spindle whilst the next length is being twisted, it is hooked through a nick at the end of the spindle.

In 1733 Mr. Wyatt of Lichfield invented a machine for spinning cotton, by which for the first time a continuous thread was spun without the intervention of the fingers; and two factories were built and furnished with his machines, one at Birmingham and the other at Northampton. The cotton was first carded by hand and then passed between two cylinders which delivered the thread on to the bobbin while in the act of twisting. Both these undertakings failed; the-

machines have long since perished and no model or detailed description of them remains. About five years later Louis Paul of Birmingham along with Mr. Wyatt proposed to spin wool and cotton by a succession of rollers, cylinders or cones, each moving proportionately faster than the preceding, to draw down the thread or sliver to any degree of fineness that might be required. The writer believes he never used such an arrangement, but simply a series of pairs of delivery rollers set in a circular form but without any drawing process. In 1742 a mill was erected in Birmingham where some of Paul's machines were set to work, driven by two asses working in a gin. He experimented for twenty years along with Mr. Wyatt, but nothing of any commercial importance ever resulted from their labours.

About 1765 two persons named Highs and Key experimented upon rollers for drawing the fibres into a continuous thread. There is no doubt but that Arkwright got some very valuable hints from them to enable him to develop the factory system. Whether Arkwright invented the drawing rollers or not, it was left for him to solve the problem how to construct a spinning machine with rollers arranged so that the first pair should draw and supply continuously a uniform sliver of parallel fibres in small portions, while a second pair should take hold of this and gradually draw out the filaments alongside of one another, and a third pair should draw the filaments out still further to the proper extent for being twisted into thread. The twisting he performed with a spindle and a fly, and the machine also wound up the thread on to a bobbin as fast as it was spun. The writer believes that Arkwright was the first to make a practical machine combining all these processes, though the question of the original invention of the drawing rollers is involved in doubt.

For the purpose of "ginning" the cotton, or separating the cotton fibres from the seed, the "roller gins" as they are called are of the most primitive construction, simply and ingeniously made, and are of Indian origin. Fig. 1, Plate 13, shows a section of a roller gin of modern construction, drawn half full size. It is formed of two small rollers about ¾ inch diameter and from 6 to 9 inches long, made to revolve in opposite directions, as shown by the arrows, by means of

toothed wheels. The bottom roller turns on fixed bearings, and the upper roller is kept in close contact with it by means of a lever and screw. The cotton seeds are fed forwards between the rollers from the table in front, a space being left between the edge of the table and the bottom roller to allow the seeds to drop down as they become cleaned of the cotton fibres by the revolving action of the rollers. A brush is fixed underneath the bottom roller to brush off any cotton fibres adhering to its surface. It is necessary that gins acting in this way should have rollers of small diameter, say from $\frac{5}{8}$ to $\frac{3}{4}$ inch, because the smaller the rollers, the more obtuse is the angle they present to the seed which is being cleaned, and the seeds are thereby better prevented from being drawn in between the rollers and crushed and mixed up with the cotton fibre. It is evident in referring to Fig. 2 that large rollers present an acuter angle to the seed, and with such rollers the seeds would unavoidably be drawn in and crushed and mixed with the fibre. The great object to be attained in ginning cotton is to get it free from all impurities; and it is found that the smaller the rollers and the slower their motion, the cleaner is the cotton fibre separated from the seeds: for if the rollers are above an inch in diameter and if they revolve very rapidly, they draw in soft, small, and false seeds, crushing them in their passage, and straining and otherwise injuring the cotton fibre.

The most improved gin of the roller class is shown in Fig. 3, Plate 13, drawn half full size, and is constructed with one large roller covered with leather and having small spiral grooves formed round it both right and left. A guard plate A is fixed near the surface of the roller, having a grating along its bottom edge just wide enough for the seeds to pass through to the roller; and between it and the roller a thin steel striker blade B vibrates a short distance up and down with a rapid motion. By this means the seeds are shaken and turned round in contact with the surface of the roller revolving in the direction of the arrow, and the cotton fibres are drawn between the blade B and the roller, while the stripped seeds are rejected and drop down through the space between the blade B and the edge of the feed table, having been thus cleaned of their fibres in a most thorough manner.

In 1793 Mr. Whitney of America invented a machine known by the name of "Whitney's saw gin," which is shown in Fig. 4, Plate 13. It consists of a wooden cylinder with a series of circular saws C, about 8 inches diameter, fixed upon it at regular distances. The edges of the saws project a short distance through a grid, the divisions of which are too narrow to permit the seeds to pass through. Care is taken that the saws revolve in the middle of the grid spaces, for if they rubbed against the bars they would tear the cotton filaments to pieces. A cylinder with brushes D, the tips of which touch the saw teeth, sweeps off the adhering cotton wool from the teeth of the saws by revolving in the opposite direction to the saw roller. The cotton seed as picked from the pods is thrown into the hopper E, and the saws in turning round snatch the filaments from the seed which remains against the grid, and drag them inwards and upwards. The stripped seeds being too large to pass through the grid accumulate at the bottom of the hopper E and are let out at intervals.

The cotton after a further process of cleansing and carding is then ready to be operated upon by the drawing frame, shown in Fig. 5, Plate 14. Five or six cans F placed side by side contain each one sliver of cotton as delivered by the carding engine, and the several slivers are drawn together and combined into one by passing through the drawing rollers G, from which the combined sliver is conducted by the funnel and rollers H into the can I in front of the drawing frame. This process is repeated by combining five or six of the new slivers into another compound sliver by passing them a second time through drawing rollers; and for the manufacture of the finer descriptions of yarns this drawing process is repeated as many as half a dozen times.

In the construction of the drawing rollers G, Fig. 5, Plate 14, the lower roller, which is the only one driven, is of iron and fluted on the surface; the top roller, which has a soft yielding surface, is driven only by friction from the lower roller, upon which it is pressed by a weight J suspended from a bearing in the centre of each roller, as shown half full size in Fig. 6. The pair of rollers are shown in

elevation, half full size, in Fig. 7, Plate 15, K being the centre bearing from which the weight is suspended; and the ends of the top roller are plain pivots LL working between vertical guides over the centre of the bottom roller, and free to move vertically, as seen in the transverse section, Fig. 6.

In the first introduction of the new system of drawing cotton by rollers a great difficulty to be overcome consisted in the cotton lapping round the rollers during the drawing instead of being delivered clear of them; and there was also the difficulty of finding a material for the top rollers that should have an elastic surface and yet be durable and perfect in its action, imitating the delicacy of touch of the human fingers in the original distaff spinning, by giving constantly the exact amount of pressure required for drawing the fibre uniformly, so as not to over stretch the thread and thereby vary the thickness of any portion. Top and bottom cleaners M, Fig. 6, Plate 14, consisting of a rubber of flannel fixed on a board lying upon the top roller and held up under the bottom roller by a weight, were applied to prevent the cotton from lapping round the rollers; and previously it had been the practice for the attendant to rub the roller occasionally with chalk, which was the plan adopted by Arkwright and continued long after his time. The application of top and bottom cleaners has to a great extent removed that evil.

The construction of the rollers is a point of great importance, upon which the success or failure of the drawing process really depends. The ordinary top rollers are those made with an iron centre, painted with white lead and covered with thick felted flannel made for the purpose, over which is placed a cover of specially prepared leather. The importance of good top rollers in spinning cannot be over estimated; but as hitherto constructed in the manner just described they have several radical defects, which make it impossible to spin or draw cotton of uniform thickness or "counts." The top rollers are made in pairs with two roller surfaces or "bosses" as they are termed upon one spindle, and as ordinarily constructed these two bosses are solid upon the spindle. Practically it is impossible to get the two bosses of exactly the same diameter when clothed, owing to the varying thickness of the leather. Then if one

of them be 1-16th inch larger in diameter than the other when covered, the result will be a contention for speed between the two bosses; for by the time one has made 20 revolutions the other wants to have gone 21. This causes slipping and abrasion of the surface of the leather, which causes the cotton to lap round the roller, and wastes the fibre of the cotton drawn, besides destroying the leather; and the roller also gives out irregular lengths of yarn or sliver. Again the ordinary roller requires oiling many times a day, owing to the bearings being all external and soon getting dry from the flakes or particles of cotton collecting about them and soon absorbing the oil; and in proportion as the bearings get dry the top roller drags and loses its speed, and the yarn or sliver becomes thicker. When oil is applied the roller goes freely for a time, giving out a greater length of sliver. By this frequent necessity for oiling not only is a great waste of oil occasioned, but the oil saturates and helps to destroy the cloth and leather covering of the roller, producing extra sticking and waste of the cotton.

Figs. 7 and 8, Plate 15, show half full size the most improved construction of these top rollers, the invention of Mr. Evan Leigh of Manchester. N N are the two bosses of the top roller, which are both loose upon the spindle, and G G is the corresponding bottom roller. The bosses of the top roller in this case revolve entirely upon the spindle, and the spindle remains stationary, instead of revolving within the hook that carries the weight and between the end guides as in the old plan. A section of one of the bosses of the top roller is shown in Fig. 7, showing the conical form of the end journals L L of the spindle, which in conjunction with the coned holes at the ends of the rollers gives a capillary action always drawing the oil from the end bearings L inwards into the parallel portion of the spindle inside the roller. The inner ends O of the spindle are coned down in a similar manner, and the oil is thus prevented from escaping from either end of the rollers. The body of the rollers N N is of cast iron, bored out with great accuracy and care, and is covered first with flannel and then with leather. The spindles are also of cast iron, and the weight for giving pressure to the top rollers is suspended from the centre K between the two bosses. Each boss N can now run at

its own speed independent of the other, and thereby each delivers out correctly its proper length of sliver. The leather keeps smooth, and saves waste of cotton; and the bearings being internal and completely covered, the roller does not require oiling for weeks. These top rollers save the couplings of the lower rollers by taking less power to drive them, and avoiding the retarding action like that of a break, which was produced by the upper roller slipping over the fluted surface of the lower roller to the extent of the variation in diameter of the bosses on the upper roller. The spindle being made of cast iron as well as the roller, the tendency to wear is reduced to a minimum; for when two surfaces of cast iron have worked together a short time, the oil becomes absorbed in the pores of the metal, which attains a high polish, runs light, and becomes as hard and indestructible as glass. These top rollers run from one to six months without lubrication, according to the quality of oil used.

Another difficulty that spinners have had to contend with is the fluting or cutting up of the leather surface of the top roller by the action of the flutes in the bottom roller. When this occurs the fibres of the cotton get crimped and cut or broken in the act of being drawn, by passing between the two corrugated surfaces, and a greater length of thread is delivered than when the top roller is kept perfectly smooth: but the spinning of good yarns depends upon the regularity of all the threads as to quantity of fibre and length delivered. The bottom rollers were formerly fluted by longitudinal grooves cut with a tool at equal pitch all round the roller, and the impression left upon the top roller was consequently of uniform pitch, and continued deepening by the pressure of the corrugations always coming upon the same parts.

About twenty-five years ago a simple method of fluting the bottom rollers irregularly was introduced with a view to remove or correct the fluting of the leather rollers; this plan is illustrated in Figs. 9 and 10, Plate 15. The ordinary roller fluting machine may be said to be an ordinary planing machine with the addition of a ratchet motion to turn the roller from one flute to the next after each cut. The method of fluting the rollers with irregular flutes was as follows. A disc P

was keyed upon the end of the roller G, on which a ratchet plate R was placed eccentric to the centre S of the roller and disc P. The click T of the ratchet moved the ratchet one tooth round after every cut of the tool U, and thus the flutes nearest to the centre of the eccentric ratchet R were closer together than those further removed from that centre, and therefore the more eccentric the ratchet the greater was the disproportion of the distances between the flutes. This is illustrated by the two segments shown by the dotted lines in Fig. 9, which at their outer extremities are the same width, namely the breadth of one tooth of the ratchet R; but where they intersect the circumference of the roller at V and X, the distance of V from the centre of the ratchet being double that of X, the breadth of the segment at that point and consequently the pitch of groove cut is also doubled. This arrangement to a certain extent obviated the tooth and tooth action which took place in the ordinary regular fluted rollers, the irregular pitch of the flutes in the new method causing their impressions upon the top roller to vary in position at each revolution; but it was not effective in saving the top roller unless there were considerable difference in the breadths of the flutes, which gave rise to another evil, namely irregular drawing of the cotton fibre: in fact in this plan a bad drawing roller was used to save the top roller.

The latest improvement in the fluting of spinning rollers was introduced by the writer about three years ago and is now being extensively adopted. Up to that time all rollers for drawing cotton and other fibres had been made with straight flutes parallel to the axis of the roller. The improvement now made in the fluting consists in forming the flutes spirally on the rollers, at an inclination of about 1 in 12 to the axis of the roller, as shown in Fig. 7, Plate 15, the grooving being done in the ordinary fluting machine with the simple addition of a twisting motion for the roller while in the act of cutting, similar to a rifling action in gun manufacture. By this means the upper roller rests upon several flutes at once, their number depending upon the length of each roller and the length of twist of the spiral flutes, instead of resting upon one straight flute as in the ordinary roller. In the ordinary roller, the flutes being parallel to the axis,

the upper roller must make a slight ascent and descent in passing over the top and groove of each flute; while with the spiral flutes the top roller is uniformly supported and will not have the least rise and fall. A further improvement is made by inclining the flutes of one roller in the reverse direction to those of the next, as shown in Fig. 7; so that by turning end for end the top rollers, which are in short lengths, any tendency of the leather to flute may be corrected, since the flutes formed by one roller would be wholly or partly effaced by the reverse spiral of the flutes in the other roller.

All the forms of rollers that are grooved in a planing machine have a defect from the edges of the grooves being left keen with a slight burr upon them, which would cause the cotton fibre to adhere to the surface of the rollers. To prevent this a careful and tedious hand process has to be gone through with each roller, after cutting the flutes, in order thoroughly to smooth down the grooves by longitudinal rubbing with stone and emery; and the rollers are then polished by revolving in the same direction in which they are intended to run in working.

A very rapid method of manufacturing these spiral fluted rollers by means of a milling tool has been introduced by the writer, in which the whole process is completed at one operation, leaving the roller finished ready for putting to work without any intermediate preparation being required. The machine for this purpose is represented in the front elevation, Fig. 13, Plate 16, and the transverse sections, Figs. 14 and 15, Plate 17; and Figs. 16 and 17, Plate 18, are enlarged views showing the details of the milling process, drawn half full size. The roller A to be fluted is laid on friction rollers B B, Figs. 16 and 17, supported by adjustable stands upon a saddle C C fixed on the main bed of the machine, Figs. 13 and 14. The milling tools D D, shown full size in Figs. 11 and 12, Plate 15, are steel discs about 2 inches diameter, and $\frac{3}{8}$ inch wide on the edge which has upon it a counterpart of the flutes to be impressed upon the roller. Each milling tool is carried by a cranked lever E working on a centre at E, Figs. 14 and 15, Plate 17, and acted on by the weight F, which exerts a downward pressure upon the milling tool of about 1200 lbs., regulated by

shifting the weight F to the extent required. The milling tools are thrown out of action by the eccentric shaft G being turned half round, which depresses the tail end of each of the four levers E, lifting the weights F, and raising the mills D from off the roller, as shown in Fig. 15, Plate 17. The mills are first placed about $\frac{1}{8}$ inch upon the ends of each roller to be cut, as shown dotted in Fig. 16, Plate 18; four roller bosses all on one solid spindle are milled at one and the same time. The roller to be milled is turned by the driving pulley H, Fig. 13, Plate 16, through a universal joint I, in order to prevent any strain upon the roller during the process. The milling tools with their levers and weights are all carried by a sliding carriage J J, and traversed along the bed of the machine by a screw K with a self-acting feed, as in an ordinary slide lathe. When the carriage J has traversed the length of one of the bosses of the roller, the machine is stopped by the handle and strap rod L; and the mills are lifted up from off the roller by turning the eccentric G. The carriage J is then moved forwards by the handle M, on which is a pinion working into a wheel on the same shaft as the crown wheel N gearing into the traversing screw K. The four mills are thus brought into a position to start milling the four remaining bosses of the roller. The weights F are then let down, causing the mills to bear on the roller; and the crown wheel N being locked by the handle O, the carriage J will then traverse the mills over the bosses. The mills work at the rate of 60 revolutions for 1 inch of traverse, the roller revolving at the rate of about 120 revolutions per minute; and the mills being about double the diameter of the roller, the fluting advances about 1-120th inch in each revolution of the roller.

Rollers manufactured in this way by milling have a much harder surface and will consequently wear much longer than those fluted by the ordinary cutting system, the surface of the metal being condensed by the pressure in the milling process. Another advantage is that the grain of the iron is laid in the best direction for ensuring smoothness of action in the working of the roller, since the roller is driven in the milling process in the same direction in which it is intended to run in the drawing frame; and the mill leaves it sufficiently polished to be immediately used for drawing.

The drawing rollers are from $1\frac{1}{4}$ to $\frac{5}{8}$ inch diameter, and 16 to 22 inches length, with from two to eight bosses of proportionate length upon each; and the several rollers are coupled together by square spigot and socket joints formed on the ends of the rollers, as shown in Fig. 18, Plate 19, extending to a total length of 30 to 120 feet, all driven from one end. The manufacture of spinning rollers has of late years been much improved by the introduction of special self-acting tools for each operation. First, the bar of iron is cut up into lengths, which are then heated and rolled between three rollers to make them true and straight. Secondly, rough squares are forged at one end of each bar with a Ryder's hammer, to form the spigot. Thirdly, each bar is cut to the exact length required, and a hole is bored up longitudinally about 3 inches at the other end, as shown full size in Figs. 19 and 20, Plate 19, six rollers being bored at a time in a multiboring machine. Fourthly, the round holes thus bored are squared out for the coupling by means of three punches, as shown in Figs. 21, 22, and 24, each punch larger and shorter than the preceding, so as to allow room for the shavings to lie at the bottom of the hole, as seen in the longitudinal section, Fig. 23. The last punch, Fig. 24, does not entirely square the hole, leaving a space to allow the air to escape from behind the punch in order to prevent risk of bursting the socket; and thus a portion of the original circle is retained on each side of the square socket for centering the roller truly in the subsequent turning process. For squaring up the spigot end of each roller, Figs. 25 and 26, four or six of the rollers are put upon a machine with as many vertical tools, and two opposite sides of the square are cut at once by a pair of tools, the roller being carried by the centres at the ends so as to ensure the square being truly central with the roller. The roller is then turned one quarter round and the remaining two sides are cut in the same manner as the two former ones. The rollers are then fitted into one another, as shown in Fig. 18, and marked as they are intended to work in the spinning machine; and they are turned in pairs to ensure their running true. They are then ready for the fluting machine already described.

Figs. 27 and 28, Plate 20, show a set of drawing rollers drawn full size. P and R are the carrying rollers, in which the top rollers

are sometimes made of iron, smooth or corrugated, and sometimes covered with leather, P being the back or feeding rollers; and S are the main drawing rollers, the upper one covered with leather, which run about seven times the surface speed of the first rollers P. In Fig. 27 the three pairs of rollers are placed close together for short fibred cotton, and Fig. 28 shows them further apart for long fibred cotton. As the different qualities of cotton vary in length of fibre from $\frac{5}{8}$ to $1\frac{1}{8}$ inch, the proper adjustment of the rollers is absolutely necessary for perfectly attenuating the mass of fibres passing through the drawing rollers. The distance from the centre of one pair of rollers to the centre of the next pair, or the "nip" of the rollers as it is called, should in no case be less than the greatest length of the cotton fibre, or else the fibres would get broken or pulled asunder by being still held by the back rollers when caught at the front end by the drawing rollers running at the higher speed. If on the other hand the successive pairs of rollers were too wide apart, the shorter fibres would not be taken hold of in a perfect manner, not being caught hold of by the quick rollers soon enough after being let go by the former rollers, thereby making a false or irregular thread.

A set of drawing rollers and a bundle of fibre is shown in Fig. 29, Plate 20, the rollers being drawn full size, with the actual distance between the successive pairs longitudinally, but with the vertical space between the two rollers in each pair exaggerated for the purpose of illustrating the nature of the drawing action: PP are the back or feeding rollers, and SS the main drawing rollers. It is of the greatest importance for the production of good and regular yarn that the sliver of cotton fibre should be regular in thickness, and also fed in with a regular continuous motion. In order to illustrate the action more clearly, the fibres are represented in the diagram, Fig. 29, alternately white, shaded, and black; and the length of the fibre corresponds with the distance from centre to centre of the successive pairs of rollers. The number of fibres in the sliver entering the feed rollers PP is represented as 10 in the diagram; and the ratio of speed of the second pair of rollers RR to that of the first pair being taken for the purpose of the diagram as 10 to 7, the fibres get drawn out past one another until they represent 7 fibres in thickness under the second pair of

rollers R. The third pair or main drawing rollers SS run quicker than the second pair in the assumed proportion of 7 to 3, and consequently the fibres passing through the third pair S are represented by 3 in thickness of sliver. Thus the sliver or bundle of fibres in passing through the three sets of rollers would in this case be diminished in thickness in the proportion of 10 to 3, and increased in length in the same proportion: so that the greater the difference of speed between each pair of rollers, the finer is the yarn produced. In practice the third or main drawing rollers S run about seven times the surface speed of the first rollers P, as previously stated; so that the sliver of fibres is reduced seven times in thickness of fibre, and increased seven times in length. It is said that the first inventors of the drawing rollers got their ideas from the action of rollers drawing or rolling iron; but it is evident that the drawing out of the fibres of iron for the purpose of elongating a dense mass of material is performed on a very different principle from the drawing action produced by a series of rollers running at different speeds on a large number of short loose fibres of fragile texture.

The spinning of short fibred cotton is practically limited by the smallest diameter that the drawing rollers can be made so as still to allow of constructing coupling sockets in the several lengths of the rollers, sufficiently strong to transmit the power required for a long length of rollers. The great bulk of the cotton machinery in this country is made for drawing cotton having a length of fibre or staple of 1 to 1¼ inch, comprising the better qualities of cotton, namely

New Orleans and African cotton	1 to 1¼	inch length of fibre
Brazil	1 to 1¼	„
Egyptian	1 to 1⅜	„
Sea Island	1¼ to 2¼	„

as shown full size in the diagram, Fig. 30, Plate 20. But the cotton from the new sources of supply now being introduced has a much shorter length of fibre, namely

East Indian and Nankin cotton	⅝ to 1	inch length of fibre

as shown in Fig. 30; and for the purpose of drawing this cotton it is requisite that the diameter of the rollers should not exceed ¾ inch, in

order to bring them close enough together to deal with $\frac{5}{8}$ inch fibre. The roller bearings are made to slide transversely, as shown in Fig. 6, Plate 14, so as to be accurately adjusted to the particular length of fibre in each sample of cotton to be drawn; and the rollers have to be small enough for the shortest fibre intended to be drawn.

Wrought iron is not satisfactorily applicable to rollers of so small a size as $\frac{3}{4}$ inch diameter when carried to a great length; for in addition to the weakness of the couplings the total amount of torsion in a long length of rollers causes the time of action to be sensibly different at the two extremities of the machine, so that the delivery is too slow in starting at the far end, thus giving an undue stretch upon the yarn and occasioning breakage at those parts. To obviate this difficulty a trial has recently been made by the author's suggestion of Bessemer steel instead of wrought iron as the material for the rollers, and this has been successfully adopted in some mills. Steel rollers have been formerly tried in a few cases, but the great expense prevented their adoption; whereas the moderate cost of the Bessemer steel admits of its use, whilst its fine homogeneous quality renders it specially suited for the purpose. A sample of these rollers is exhibited, together with working models of a box or set of drawing rollers, throstle rollers, and mule rollers.

Mr. Weild exhibited a drawing frame in action containing a set of the spiral fluted rollers and the improved top rollers; with specimens of the fluted rollers in different stages of the manufacture, and of the Bessemer steel rollers, and the milling tools employed for milling the rollers; also a specimen of the roller gin for cleaning the cotton from the seed.

The Chairman thought the plan now described of milling the drawing rollers by the pressure of a milling tool, instead of cutting each groove separately in a planing machine, was highly ingenious;

and in combination with the spiral direction of the grooves must be most beneficial in preserving the leather surface of the top rollers from injury by indentation. The employment of Bessemer steel for the rollers appeared an improvement of special value at the present time, if it would enable the new short-staple Indian cotton to be drawn and manufactured with the same facility as the old American and other cotton of greater length of staple, by the adoption of drawing rollers of smaller diameter than those hitherto used. He enquired to what extent the small diameter rollers of Bessemer steel were now employed, and how long the spiral fluted rollers had been introduced.

Mr. WEILD replied that a mill at Preston was the only one at present furnished with the small rollers of Bessemer steel; but the spiral fluted rollers grooved by the milling process had been introduced about 3½ years ago, and were now being employed in more than three hundred mills in Lancashire and Yorkshire. During the last twelve months great numbers of the old rollers had been replaced by the spiral milled rollers, the stoppage of the works for want of cotton affording a good opportunity for making the change.

The CHAIRMAN enquired whether the smaller rollers could be applied with equal facility to the long fibred cotton, if the latter were again supplied in the same abundance as formerly.

Mr. WEILD thought there would be no difficulty in applying the small rollers to the long fibred cotton; it would only be necessary to move the successive pairs of rollers further apart, to correspond with the greater length of fibre, which was easily done, as the roller bearings were carried in slots so as to admit of any adjustment horizontally: and the difference in the degree of contact of the top leather roller upon a bottom roller of 1 inch diameter or upon a bottom roller of only ⅝ or ¾ inch diameter was so slight that it was scarcely capable of producing any perceptible difference in the drawing of the cotton. The prejudice against using small diameter rollers was owing to the expense attending their introduction into the present drawing frames; because it was not merely that the large rollers were removed and replaced by the small ones, but for this purpose the whole of the roller stands had to be removed and replaced by others having the roller bearings closer together, in order to suit the smaller

diameter of the rollers, which involved a very heavy expense. The change was now being made in another factory at Preston. He showed a specimen of a roller frame fitted with a set of the small rollers, the front and back pairs of rollers being $\frac{3}{4}$ inch diameter, and the middle pair $\frac{5}{8}$ inch diameter.

The CHAIRMAN asked what was the speed at which the rollers could be grooved by the milling process, as compared with the old method of planing the grooves; and also how the mills were made.

Mr. WEILD replied that by the milling process a roller could now be completely grooved ready for use in less time than it took to fix the roller for cutting in the old planing machine and get the machine ready for work. It took about $1\frac{1}{2}$ minutes to mill a roller of eight bosses, milling four at a time. For making the mills a master roller was first made of exactly the diameter of one of the bosses of the drawing rollers, which was fluted spirally in a planing machine with grooves of the exact depth and pitch required, and afterwards casehardened. The soft iron mills were then put in the milling machine, and were themselves milled by the hard master roller, and afterwards casehardened. The iron used for the mills was made from scrap consisting of "card teeth," the fine wire teeth of the carding machines: the mills were thus not steel, but iron casehardened, which was found more suitable, since the best steel was found to crack and fly under the heavy pressure of milling. What was wanted was a hard and tough quality of metal, having a surface hard enough for indenting the rollers in milling, but not so brittle as to crack under the pressure; and these qualities were admirably combined in the casehardened iron made from the card teeth. It was now a regular trade in Manchester to make that iron from the card teeth to be used for the engraving rollers employed in calico printing; and for that purpose no kind of steel would do that had the least flaw in it. He showed specimens of the mills that had been in constant work for six months and were not worn out yet, exhibiting scarcely any signs of wear at present. He showed also a specimen of a roller milled to a much greater depth with two opposite spirals of rapid pitch, producing a deeply "pitted" or grated surface; such rollers were required for drawing off the cloth from looms, and were previously made by

punching a piece of sheet iron in the manner of a grater, and wrapping it round a wooden roller with the rough side outwards.

The CHAIRMAN remarked that the homogeneous character of the Bessemer steel would be a great advantage in the manufacture of the drawing rollers, and its superiority to ordinary steel in that respect was clearly seen in the two specimens of rollers now exhibited, one of the Bessemer steel and the other of ordinary steel, the latter having its surface full of minute lines while the former appeared perfectly homogeneous and free from even the faintest appearance of marks. In respect of strength, he had tested a great deal of the Bessemer steel, and found it had nearly double the tensile strength of the best wrought iron.

Mr. WEILD observed that the steel he had used for the small drawing rollers was not the best Bessemer steel, but was obtained at a cost of about £25 per ton. It was completely homogeneous and free from cracks, and answered the purpose very well for the drawing rollers. It was not necessary to make the rollers of the very best Bessemer tool steel, because they had not to be tempered after the milling.

Mr. J. FERNIE thought the new mode of fluting the rollers was a beautiful and ingenious application of the milling process and much superior to any plans of milling previously in use. He enquired whether any attempt had been made to apply the same method of milling for making rimers for rimering out circular holes.

Mr. D. JOY observed that the milling process had the effect of rounding the edges of the grooves instead of leaving them square and sharp as in the former planed grooves; but a rimering tool required square cutting edges, not rounded off, which could not he thought be obtained by milling.

Mr. WEILD said he had not tried the milling process for any other purpose than that described; and there was a sort of tooth and tooth action between the milling tool and the roller, whereby the edges of the grooves were necessarily rounded off, which was an advantage in the make of drawing rollers. The success of the operation depended on taking in very small portions of the surface successively to be acted upon by the mill: if it were attempted to mill one of the rollers by

placing the whole of the $\frac{3}{8}$ inch edge of the mill upon the roller at once, it would be impossible to indent the surface; but by beginning with a very small length of roller under the mill, and advancing the mill lengthwise on the roller only 1-120th inch in each revolution of the roller, the fluting was accomplished without any excessively severe pressure; and the remaining portion of the edge of the mill acted as a polisher following the milling, so that the flutes were milled and polished all at one operation. The result of using the milled rollers was that, in consequence of the roundness of the edges of the flutes and their spiral direction, the leather of the top rollers continued in good condition with a smooth surface for a much longer time; and this was a very important point, since a nice even yarn was obtained in spinning as long as the leather remained uninjured, but not after its surface became roughened by wear.

Mr. J. Fernie enquired how the rollers were got true in line and diameter, so as to run perfectly steady for such a long length as 130 feet, made up of so many short lengths jointed together.

Mr. Weild explained that all the coupling sockets and spigots were cut by machinery, the rollers being accurately centred on the same centre holes in each operation, whereby perfect truth of work was obtained. The bar to form the roller, after being forged roughly at one end to the required square for the spigot, had a centre hole drilled at each end for centering it in the boring machine, where the socket hole was drilled and afterwards squared out to the exact size by three punches, working longitudinally and following one another in the hole: the roller was then centred by the same centres in an upright slotting machine for squaring the spigot end, and the two opposite sides of the square were cut simultaneously, after which the roller was turned one quarter round, and the two other sides cut in the same way. The rollers were then fitted together and marked, and afterwards turned in pairs in the lathe: Nos. 1 and 2 were first turned together; then No. 1 was removed, and No. 3 was turned with No. 2; then No. 2 was removed, and No. 4 turned with No. 3; and so on. By this means the whole length of a long line of rollers was made to run perfectly true.

Mr. J. Fernie asked how the covering of the top rollers with leather was performed.

Mr. Weild explained that the cast iron boss of the roller was first painted and covered with a layer of felted flannel; and then the leather was wrapped round outside by machinery, and a knife in the machine set at an inclination cut it off with a bevilled edge so as to lap accurately without increasing the thickness of leather at the joint: at the same time a glue brush was passed along the edge, sticking it down securely with strong glue. The top rollers were required to be both durable and elastic, and the leather formed a durable external covering, while the layer of flannel underneath gave the elasticity required to prevent the cotton fibres being injured in drawing.

Mr. D. K. Clark enquired what description of leather was used for covering the rollers; he understood that pigskin had been employed lately for the purpose.

Mr. Weild believed the leather generally used for covering the rollers was common sheepskin, prepared slightly for that particular purpose.

The Chairman proposed a vote of thanks to Mr. Weild for his paper and the numerous specimens he had exhibited, which was passed.

The following paper was then read:—

ON THE LOCOMOTIVE ENGINES IN THE INTERNATIONAL EXHIBITION OF 1862.

By Mr. D. K. CLARK, of London.

The collection of Locomotive Engines shown in the International Exhibition of 1862 may be adopted as a fair average exponent of the best and most recent practice both English and Foreign, particularly the former. The English engines were mainly examples of the standard classes in general use on the principal English railways. The Foreign locomotives showed greater variety, boldness, and originality of design, and were mainly constructed for lines with very heavy gradients and sharp curves, which are generally associated together in mountainous districts, causing special mechanical difficulties not applying to the general circumstances of the English railways.

Twenty engines altogether were exhibited, of which eleven were contributed from the United Kingdom, three from France, one from Belgium, two from Austria, one from Prussia, one from Saxony, and one from Italy. Of the above twenty engines, fourteen had outside cylinders, and six had inside cylinders; and of the eleven English engines seven had outside cylinders, and four had inside cylinders. Most of the engines were specially constructed for burning coal: a feature which has been introduced entirely since the former Exhibition of 1851, on account of the smaller cost of coal for fuel compared with coke. The principal particulars of the locomotive engines exhibited, both English and Foreign, are given in the Table appended.

English Locomotives.—Amongst the English locomotives may be noticed first, as specimens of the largest class of Express engines, two exhibited and manufactured by the London and North Western Railway, one with inside and the other with outside cylinders, but both with 7 ft. 6 ins. driving wheels, and designed with special regard to the running of the express trains on that line.

Of the Inside Cylinder class only three engines were made, as it was found to be heavy on the road and in consumption of fuel. It is an engine of maximum dimensions, and indeed must be considered beyond the capacity of the narrow gauge for proper working. With cylinders of 18 inches diameter and a stroke of 24 inches, 7 ft. 6 ins. driving wheels, and 26 square feet of grate, it weighs 34¾ tons in working order, of which there are 14¼ tons on the single pair of driving wheels. With the tender, weighing 25 tons with fuel and water, the total weight to be moved amounts to about 60 tons, exclusive of the train. The boiler has been designed for burning coal, with a combustion chamber and a double compartment of the firebox for alternate firing, to which have been added firebrick arches inside and deflecting plates in the doorways. The grate is 7 feet long in two parallel strips, and the enormous amount of 242 square feet of heating surface has thus been attained in the firebox and the combustion chamber; making the "direct" heating surface greater than has before been attained on the narrow gauge. But the advantage of "direct" surface, or that which is exposed to the radiant heat of the fire, depends upon its being within a reasonable distance of the grate; whereas in this firebox the crown is 6 feet 3 inches above the grate, and the upper portions of the surface are therefore nearly ineffective for evaporation. This great extension of firebox and combustion chamber has led to the curtailment of the tubes to 9 feet 4 inches length, and it has been attempted to compensate for this by packing 214 tubes together at ·50 inch distance apart, making 980 square feet of heating surface in the tubes. The opinion has been extensively held that heating surface is mechanically the equivalent of evaporating power, but this in the writer's opinion has not been confirmed by practice; for besides surface, circulation is wanted; the circulation of the water to the tubes, and of the steam from amongst them: and in this particular engine the evaporative power of a smaller number of tubes placed at ·75 inch apart would have been greater than that of the tubes as they are. The driving and leading springs are connected by a compensating beam, which seems likely to give an unsafe freedom of action to the engine at high speeds.

The Outside Cylinder engine, exhibited by the London and North Western Railway, is one of a numerous class running the express trains on that line, and contrasts in several respects with the inside cylinder engine. It weighs only 27 tons in working order, and the tender 17½ tons, making a total of 44½ tons, as against 60 tons for the other engine; and the weight on the driving wheels is only 11½ tons instead of 14¼ tons. The weights on the several wheels are,

	Inside Cylinder engine.	Outside Cylinder engine.
Leading wheels	11·90 tons	9·40 tons.
Driving wheels	14·30 "	11·50 "
Trailing wheels	8·50 "	6·10 "
Total weight	34·70 "	27·00 "

The firebox is of the ordinary form, with little more than half the grate surface of the other engine; and it is fitted for coal burning with a firebrick arch and two air openings in front, closed by a regulating flap, as shown in Figs. 1 and 2, Plate 21, which show a longitudinal and transverse section of the firebox. The heating surface of the firebox is 85 square feet, being little more than one third that of the inside cylinder engine; and there are fewer tubes, but then they are ·62 inch apart. The other engine gains the advantage in the greater size of blast orifice, which is 5¼ inches diameter for the inside cylinder engine, and 4½ inches for the outside cylinder engine; owing to the larger area of grate in the former engine, which does not require the same sharpness of blast to draw the air through.

Regarding the engines as carriages, the height of the centre of the boiler in the inside cylinder engine, 7 feet 5½ inches above the level of the rails, is considerable, and tells upon the rails when the engine sways. In the outside cylinder engine, though the driving wheels are as large, the centre of the boiler is 11 inches lower; and this in connexion with a compact wheel base and a balanced driving wheel, produces a safe steady and easy-running engine. In both the engines feed pumps are displaced by two Giffard's injectors.

The outside cylinder engine is fitted with a duplex direct-action safety valve, in which a pair of valves are pressed down by a crossbar with a spiral spring attached to the middle of the bar, between the two valves, as described at a former meeting (see Proceedings

Inst. M.E., 1856, page 37); a decidedly superior arrangement to the ordinary weighted lever, since this valve cannot be tampered with, and is much more prompt in discharging an excess of steam, as it opens wider for a given excess of pressure. The smokebox is furnished with a descending hopper at the bottom, having a small opening not closed, through which ashes and ignited cinders are allowed to escape constantly; thus overheating of the smokebox is prevented. The reversing gear is worked by a screw and handwheel, instead of the usual long lever and notched sector; this reversing gear, which is applied to nearly 200 engines, is more easily worked, saving the engineman a great deal of fatigue.

The tender of this engine, exhibited with it, has six wheels, and weighs empty 9½ tons, full 17½ tons, the load being equally distributed on the wheels. It is fitted with the apparatus for picking up water whilst running, as described at a former meeting of the Institution (see Proceedings Inst. M.E., 1861, page 43): a scoop is let down from the bottom of the tender, and dips into the water contained in a long open trough between the rails, from which it is made to flow up the scoop into the tender tank by the motion of the tender in running. A minimum speed of more than 15 miles per hour is required for this operation. Three of these water troughs have now been laid down and are in use in different situations on the London and North Western Railway; and their advantages are that the size and weight of the tender for running a given distance may be reduced, the number of stoppages lessened, and time saved. An express engine has thus been enabled to run the whole distance from Holyhead to Stafford, 130½ miles, in one continuous run, without a single stoppage, at an average speed of 54½ miles per hour.

The next engine to be noticed is a Passenger Express engine, for the South Eastern Railway of Portugal, 5 feet 5¾ inches gauge, exhibited and manufactured by Messrs. Beyer Peacock and Co., whose design is characterised by elegance, thoroughness, and finish, in form, arrangement, and detail. This engine is a type of the prevalent style of English inside cylinder express engines. The framing is composed of two pairs of longitudinal bars or slabs running straight from end to

end, cross-braced by the cylinders, the footplate, and various cross plates. The extension alongside the firebox of the two inside longitudinal slabs, which stopped short in front of it in the earlier examples of this description of frame, is a great improvement in practice, as it connects the steam cylinders, driving axle, and drawplate directly and immovably together, and bears the entire strain of the steam in the cylinders and transmits the tractive force to the train. The boiler is thus relieved of all strain from the working parts, from which formerly it was not free and then suffered accordingly. The driving axle is made with only two bearings, inside the wheels, for which the guards are forged on the inside frame plate, and the leading and trailing wheels have their bearings outside the wheels; an arrangement originated by the late Mr. John Gray, and now generally adopted for its simplicity, and for the greater firmness of the frame and the increased duration of the crank axle. The steam strain is in fact confined to the two inside frame plates, and to the inside bearings of the crank axle, close to the cranks. The leading and trailing wheels are 3 feet 9 inches diameter, the driving wheels being 7 feet: the leading wheels have been thought rather too small, and no doubt there is space in the engine for enlarging them; but they would have departed from uniformity with the six tender wheels, which also are 3 feet 9 inches diameter.

The short cast iron blast pipe reaching just above the level of the upper row of the tubes is to be remarked. This level of blast orifice has been found to give the best results, creating a better draught with a wider orifice, as compared with higher blast pipes; and was arrived at by Mr. Peacock, by means of a series of well arranged experiments on the Manchester Sheffield and Lincolnshire Railway: the low blast pipe is now generally employed. The early blast pipes were carried some distance into the chimney and had very contracted orifices, and a sharp blast with much back pressure on the piston was the consequence.

The boiler, in consequence of the greater width of the Portuguese gauge, 5 feet 5¾ inches, has a large square firebox, 4 feet 10 inches each way over the outside shell; and has a large diameter of barrel, 4 feet 2 inches, which gives abundance of steam and water space.

Nevertheless for effective heating surface a firebox of oblong form would in the writer's opinion be better. There are 215 tubes of 2 inches diameter placed at ·56 inch apart: had the tubes been only $1\frac{7}{8}$ inch diameter, which upon the whole the writer considers the best size, and placed in the same position, the larger clearance of ·69 inch so obtained for circulation would have improved the evaporative efficiency. The firebox is adapted for coal burning with a firebrick arch, a deflector plate from the doorway, and sliding firedoors, on the plan in use on the Midland Railway (see Proceedings Inst. M.E., 1860, page 147).

A Passenger Express engine for the Caledonian Railway, exhibited and manufactured by Messrs. Neilson and Co., is a specimen of the class of engines extensively used on that line, which were designed with a view to economy rather than speed, although a very large driving wheel is used; they are employed on main line service between Glasgow and Carlisle, taking their turn with all trains, fast and ordinary. From the experience that had previously been acquired of the durability and general economy of the 7 ft. driving wheels over the original 6 ft. wheel passenger engines of the line, it was supposed that a further extension of the principle of enlarging the driving wheel would be advantageous; and the extreme size of 8 feet 2 inches diameter has been adopted for trial in the class of engines exhibited: but it may be questioned whether this has not been carried too far. The cylinders are $17\frac{1}{4}$ inches diameter and 24 inches stroke. This engine has grown out of the old Crewe pattern of engine, originally introduced on the Caledonian line by the late Mr. Locke, the chief engineer, and successively modified to meet the growing requirements of the traffic. The engine weighs in working order $30\frac{3}{4}$ tons, of which the driving weight amounts to $14\frac{1}{2}$ tons. This driving weight is considerably in excess of any other among the engines exhibited, except that of the North Western inside cylinder engine; but no doubt the large size of the driving wheels, 8 feet 2 inches diameter, reduces in some degree the injurious effects of so great a concentrated load on the permanent way. The counterweights are compactly forged into the rims of the wheels, extending over one third of the circumference; and though a little

more weight is thus requisite to complete the balance, it sweeps gently over the rails when the engine is in motion, without the sledge-hammer effect of a revolving cubical mass compressed into the space between two or three spokes. For such a large wheel also the spokes are planted thickly, at 10 inches centre to centre on the rim: the stiffness of a spoke decreases in a rapid proportion with its length, diminishing as the cube of the length, so that a spoke of an 8 feet wheel will be only about half as stiff as a spoke of the same scantling for a 7 feet wheel. The driving axle is of cast steel and the tyres are of Krupp's steel.

The framing of the old Crewe engine is retained in this one, giving outside bearings to the fore and hind axles and inside bearings to the driving axle. In this respect the North Western outside cylinder engine already described is at variance with the older practice, having but one longitudinal frame plate on each side, with inside bearings for all the wheels. It may very properly become a question whether the cylinders should be so rigidly united as they are in the Caledonian engine to the outside frame plates, which carry two pairs of wheels and axles and of course transmit the shocks of the road to the cylinders. The footplate is provided with a housing for the engineman and stoker, a most important provision for their comfort and consequently for the safety of railway trains. Plain fence plates or weatherboards across the back of the firebox are now commonly applied to engines, and these are useful; but the housing is certainly better, and it seems strange that the adoption of so desirable a protection should have been so long neglected.

The slide valves are made with 1½ inch lap at each end, according to the proportion originally arrived at by Mr. Sinclair on the Caledonian Railway from finding the peculiar importance of long lap and long travel for the valves of outside cylinders. The long lap and long travel of the valves unquestionably facilitate the free exhaust of the steam at high speeds from exposed cylinders, in which the steam is more or less partially condensed: and moist steam being not so active as dry steam exerts an excessive back pressure on the piston, if not freely discharged.

The boiler is fitted with the firebrick arch and door deflector previously referred to for burning coal; the barrel is 3 feet 10 inches diameter, and contains 192 tubes of 1⅞ inch diameter, placed with ·62 inch clearance between them. Giffard's injectors are employed. The consumption of coal by these engines is stated to average 23 lbs. per mile, with trains of 9 heavy carriages and a speed of 35 to 40 miles an hour; and they take 14 loaded carriages up the Beattock Incline, an average rise of 1 in 78 for 10 miles, at a speed of 30 miles an hour.

The Goods engine for the London Chatham and Dover Railway, exhibited and manufactured by Messrs. Sharp Stewart and Co., is a first-rate six-coupled-wheel engine, with 5 feet wheels and 17 inch cylinders of maximum power, adapted for the heavy loads, heavy gradients, and the high speeds ultimately intended on that line. It is a fine engine, of excellent workmanship and proportions. It weighs empty 28½ tons, full 32 tons; and the weight is nearly equally distributed over the three axles, to the advantage of the permanent way, so that the load on any one axle does not vary more than ⅞ ton from the average load on all the axles, the loads being as follows:—

Leading wheels	10·65	tons.
Middle wheels	11·55	,,
Trailing wheels	9·85	,,
Total weight	32·05	,,

The firebox is 8 feet long externally, with an inclined grate on the South Eastern Railway plan for burning coal, as shown in Figs. 3 and 4, Plate 21, which give a longitudinal section and sectional plan of the firebox. The hind axle is thus brought under the firebox about one third of the length, and is enabled to take its proper share of the load; whilst the length of wheel base is moderated, and is bisected by the middle axle: advantages peculiar to this plan of firebox. The firebox measures 7 feet 3 inches long inside, divided longitudinally by a midfeather, as seen in the plan, Fig. 4; and has 27½ square feet of grate. There are 189 tubes, 2 inches diameter, with ·62 inch clearance, within a 4 ft. 2 ins. barrel. These are good proportions, according to current practice; but had there been

only 160 tubes with ·75 inch clearance, in such a large barrel, it would in the writer's opinion have been decidedly better. The boiler is fitted with Giffard's injector. The housing for the engineman, with windows in the front and sides, is very good and complete.

The frame is composed of four longitudinal plates, carried from end to end, with suitable cross plates to bind them. The outer plates are each of one slab, combining great strength and lightness; the usual construction of outer frame with double plates and timber packing has thus been superseded in this engine. The driving axle has four bearings, two inside and two outside, and the extreme axles have only outside bearings; and the old antagonistic action is set up, arising out of the unequal wear of the inside and outside bearings: the inside bearings next the cranks, receiving the full strain of the steam, will wear faster than the outside bearings, leaving the cranks unsupported, and shortening the duration of the axle; overstraining in that way also the connexions of the inner and outer frame plates, and thereby loosening them. On the other hand this arrangement admits of large outside bearings and capacious axleboxes for all the axles; an advantage which unfortunately the narrow gauge does not permit for inside crank-axle bearings. The drawing tackle of this engine is connected exclusively to the frame, and kept quite independent of the firebox.

The valve gear is very substantially and firmly arranged: the expansion link is shifted, and the slide block is not overhung, but hung between the ends of the link which carries it. This engine is stated to be capable, with a working pressure of 120 lbs. per square inch, of taking a load of 480 tons on a level at 20 miles an hour, or a load of 250 tons up a gradient of 1 in 100 at 15 miles an hour.

A six-wheel-coupled Goods engine of excellent workmanship for the Midland Railway was exhibited and manufactured by Messrs. W. Fairbairn and Sons. It has the ordinary rectangular firebox with 14½ square feet of grate, and is fitted on the Midland plan already referred to for burning coal. The cylinders are 16 inches diameter with 24 inches stroke. The engine weighs in working order 32¼ tons, and is a thoroughly good engine of its kind; it is a type of the powerful

goods engine usually met with on the old main lines of railway, and may be usefully compared with the Chatham and Dover goods engine last described, which is an engine of the same weight and power, but of a different and more recent class. In the first place, the weight is not so well distributed on the wheels of the Midland engine, being considerably in excess on the leading wheels, the loads being as follows:—

	Midland engine.	Chatham and Dover engine.
Leading wheels	12·30 tons	10·65 tons.
Middle wheels	11·25 ,,	11·55 ,,
Trailing wheels	8·70 ,,	9·85 ,,
Total weight	32·25 ,,	32·05 ,,

showing in the former engine 3½ tons more load on the leading wheels than on the trailing, and in the latter only ¾ ton more; while the wheel base of the former engine is 16 feet 6 inches, or 1 foot more than that of the latter, as the vertical firebox of the former keeps back the hind axle. The frame of the Midland engine, like that of the other, has four longitudinal plates, with four bearings to the driving axle and outside bearings to the other axles; but the inside frame plates stop short at the firebox, and are fastened to it by sliding joints, allowing for expansion of the boiler. The drawplates are rivetted to and across the back of the firebox, from which the whole of the drag is taken; and therefore, as the tractive force must be transmitted from the outside frame plates to the firebox, they are very strongly united to it by brackets for that purpose. Thus the whole area of the frame behind the firebox remains unemployed except as standing ground. This is in the writer's opinion an objectionable feature in the engine, without any countervailing advantage. Not only is the steam power transmitted circuitously, tending to overstrain and buckle the framing; but it arbitrarily subjects the boiler, already highly strained, to a great and unnecessary additional strain, which is now beneficially avoided in the other arrangements of the framing as already described.

The boiler tubes are well designed, being 2 inches diameter, 180 in number, and placed with ·62 inch clearance, in vertical rows; which accounts for the high character of these engines for keeping up the steam. The boiler is put together without angle iron, the plates being

flanged at the end; the steam dome also is flanged and formed in one piece. For this purpose thick-edged plates are used, rolled to $\frac{5}{8}$ inch or $\frac{3}{4}$ inch thick at the edge, to allow material to work upon in flanging. The advantages claimed for the thick-edged plates in their application are that they save a joint, including a row of rivets, and are stronger than angle iron joints; and that the joints are cheaper and easier to make, and are not subject to grooving by corrosion. The dome joints being faced in the lathe, bad joints are prevented.

Of the Mixed engines a six-wheeled four-coupled engine for the East Indian Railway, of 5 feet 6 inches gauge, was exhibited and manufactured by Sir W. G. Armstrong and Co., with outside cylinders and the hind wheels coupled. The wide Indian gauge of rails, 5 feet 6 inches, admits of a large firebox 4 feet $1\frac{1}{2}$ inches square inside, with a grate of 17 square feet, which appears too large for the cylinders of 16 inches diameter and 22 inches stroke and the wheels of 5 feet 7 inches diameter. The boiler tubes 157 in number are 10 feet 11 inches long, $2\frac{1}{4}$ inches outside diameter, and they clear one another by ·56 inch. These proportions would in the writer's opinion be improved by reducing the tubes to 2 inches diameter with increased clearance; and the reduction of heating surface would be amply compensated by the increased facility for circulation of the water and steam between the tubes.

The total weight of the engine in working order is $32\frac{3}{4}$ tons, which is too great for such an engine; $21\frac{1}{4}$ tons are available for adhesion, but very unequally divided between the wheels, the respective weights being

Leading wheels	11·47	tons.
Middle wheels	12·55	„
Trailing wheels	8·67	„
Total weight .	32·69	„

The leading wheels are 3 feet 7 inches diameter, and the six wheels of the tender are 3 feet 9 inches diameter, only 2 inches difference in size.

The slide valves have only $\frac{3}{4}$ inch lap, but this is inadequate for a 16 inch outside cylinder, in which there is always more or less

condensation of steam. The back pressure on the piston at high speeds must be considerable, as an insufficient lap prevents a full and free opening to the exhaust, which is required to be greater for moist than for dry steam. The footplate is furnished with an awning frame, to protect the engineman completely from the sun and to ensure ample ventilation: an object of vital importance in India. It is a very complete screen, the use of a weatherboard being unfavourable for ventilation.

A Mixed engine was exhibited by the Great Eastern Railway, manufactured by Messrs. Robert Stephenson and Co., with six wheels, four coupled, and outside cylinders. The framing has but one longitudinal plate on each side from end to end, with inside bearings for all the wheels. With 17 inch cylinders and 6 ft. 1 in. driving wheels, which are more powerful than in the East Indian engine, the boiler is lighter, having only 13½ square feet of grate instead of 17 square feet, with a shallower firebox and a smaller barrel. Hence the total weight of the engine is less, and the weight is more equally distributed on the wheels, the loads being

Leading wheels . . .	11·10	tons.
Middle wheels . . .	10·70	„
Trailing wheels . . .	10·05	„
Total weight .	31·85	„

The leading wheels of 3 feet 7 inches diameter are also very properly made uniform with the six tender wheels. The engine is reported to have run 45,000 miles without repairs; for which satisfactory result it is indebted to excellent design and workmanship, and no doubt also to the favourable distribution of the weight, and to the material of the tyres, Krupp's steel, which were apparently very little worn. A pair of tyres which had run 68,000 miles showed a wear of only about ¼ inch on the tread. Several of the driving and trailing wheel tyres of engines of the same class have run 60,000 to 70,000 miles without re-turning. The duration of these steel tyres is estimated at 100,000 miles on the leading wheels, and 150,000 miles on the middle and trailing wheels; but none have yet been worn out.

The barrel of the boiler is 3 feet 10 inches diameter, and has 192 tubes, 1⅞ inches diameter, with ·62 inch clearance; which are fair proportions. The firebox is fitted for burning coal, with a door deflector and jets of steam from the sides of the firebox. The slide valves have 1¼ inch lap, with 5½ inches travel in full gear: very suitable proportions for outside cylinders as before observed, for quick running and free exhaust.

Engines of this class are stated to work passenger trains averaging 16½ carriages, maximum load 35 carriages, at an average speed of 25 miles an hour, consuming 25 lbs. of coal per train mile; and goods trains consisting of 35 wagons, gross weight 300 tons, at an average speed of 20 miles an hour, consuming 30 lbs. of coal per train mile.

Of the Tank locomotives the largest is that exhibited and manufactured by Messrs. G. England and Co., weighing 17 tons in working trim. It was designed for branch lines, and has six wheels with a 10 feet wheel base, four coupled wheels of 4 feet diameter, and cylinders 11 inches diameter. It is neatly arranged, with two tanks to hold 520 gallons very conveniently placed on the footplate, one on each side, enclosed out of view by a fence carried nearly from end to end of the engine. Of the weight, which is equally divided on the axles, two thirds is available for adhesion. There are 153 boiler tubes, 1¾ inch diameter, with ·50 inch clearance, the boiler barrel being 3 feet 8 inches diameter.

A neat compact and serviceable little Tank engine was exhibited and manufactured by Messrs. Manning Wardle and Co., specially adapted and extensively used for collieries, ironworks, and public works. This engine was employed at the Exhibition under the author's superintendence in conveying the machinery on trucks from the unloading cranes to its destination in the western annex along lines of rails laid down for the purpose; a duty in which it was of essential service. It has 9 inch outside cylinders, and four wheels coupled of 2 feet 9 inches diameter, on a wheel base of 4 feet 9 inches. The area of firegrate is nearly 5 square feet; and the boiler has 55 tubes, 2 inches diameter, with ·69 inch clearance, which is amply sufficient

for circulation. The weight in working trim is 10¼ tons, equally distributed over the two pairs of wheels. The water tank is placed upon the barrel of the boiler, and holds 252 gallons. The coke boxes hold 7½ cwts. Giffard's injector is employed. With a working pressure of 120 lbs. per square inch in the boiler, the exhibitors assume an effective mean pressure of 60 lbs. in the cylinders, which appears too low but errs on the safe side; upon this they estimate the extreme tractive power as equal to moving 206 tons, but the actual power of the engine is no doubt greater.

The last and the smallest locomotive exhibited in the English section is a Tank engine for ironworks and collieries in South Wales, manufactured by the Neath Abbey Iron Co., for a gauge of 2 feet 8 inches, with 8 inch cylinders and four coupled cast iron wheels of 2 feet 4 inches diameter, 4 feet apart centre to centre. The centre of the boiler is only 2 feet above the rails. The boiler has 3½ square feet of grate, and 59 tubes, 1½ inch diameter and 6 feet long, giving a total heating surface of 181 square feet; the gross weight in working order is 6·85 tons. The tank is on the back of the boiler. The engine is carried on volute springs. The engines employed in the Neath Abbey Works have a run of nearly one mile, with gradients varying chiefly from 1 in 15 to 1 in 26, with a small portion 1 in 100; they take the return empty wagons up the incline to the coal pits, the full ones going down by themselves. With 80 lbs. pressure of steam the regular duty of the engine is to take up 16 empty wagons or trams, weighing altogether 6·45 tons or nearly the weight of the engine itself, in 7 minutes, or at the rate of 8 miles an hour. With 66 lbs. steam it can take up at the same speed 12 wagons weighing 4·50 tons.

Foreign Locomotives.—The Foreign locomotives exhibited were all made for the English 4 ft. 8½ ins. gauge.

The French department contained examples and designs of various classes of engines, some of them not known in this country. The first is an ordinary Passenger engine exhibited and made by the Orleans Railway. It has outside cylinders, with the valves and

valve gear outside the cylinders and crank pins. The firebox is constructed for burning coal, with a long sloping grate, and a transverse water partition or midfeather across the firebox, above and nearly parallel to the grate, extending backwards from the tube plate and similar in position to the firebrick arch used in English engines, so as to deflect the flame towards the firedoor and cause it to meet the air admitted there. These are merely varieties of English practice: but the outside gearing is objectionable, for besides being exposed to accident the play of the parts arising from wear injuriously affects the working of the valves in regulating the distribution of the steam, to a much greater extent than when the valve gear is inside the wheels. Giffard's injector is applied, the construction being simplified by omitting the mechanism for varying the supply of water. The axles are lubricated from below by means of cotton stumps, which lift the oil by capillary attraction from a reservoir in the bottom of the axlebox.

A six-wheel-coupled Goods engine for the Orleans Railway was exhibited and made by Messrs. Cail and Co. It has inside cylinders, with 5 ft. wheels and a wheel base of 11 feet 4 inches. It had already run 13,000 miles on the central division of the railway, where the curves are numerous and sharp and the inclines steep. The fore and hind axleboxes have ¾ inch play transversely, and are held taut by springs acting horizontally, which tend to restore them to their central position. The wheels are solid wrought iron, of excellent workmanship, welded at two heats on Arbel's plan. The rim is forged in segments, the nave in two circular halves, and the spokes are let into the rim segments and the two halves of the nave. The whole is clamped together, heated in a furnace, brought out and placed under a large hammer with suitable dies the size of the wheel, and welded on one side. The partially formed wheel is again heated, and welded complete on the other side. A first-rate piece of work can be done by this process. The counterweights are welded to the rim and spokes of the wheels. The connecting and coupling rods are of cast steel.

The Northern Railway of France exhibited the "Dromadaire" heavy Tank engine, shown in Figs. 5, 6, and 7, Plates 22 and 23. The

object specially aimed at in this engine was to obtain a considerable supply of steam and great tractive power, in combination with the smallest possible weight. For this purpose the firebox, as shown in the transverse section, Fig. 6, Plate 23, is placed above the wheels and frame plates, in order to allow of greater width, a larger grate, and more tubes than when at the usual level, without lengthening the boiler. Eleven such engines are at work on the Northern Railway of France, burning coal slack. The roof of the firebox and its shell are flat and parallel, and stayed together like the sides, Fig. 6. The steam space in the barrel is reduced to make room for the tubes, and is supplemented by a tubular steam chamber A above the boiler, as shown in the transverse section, Fig. 7, containing 19 iron tubes, $3\frac{1}{8}$ inches outside diameter and $\frac{1}{8}$ inch thick, giving 129 square feet of drying surface, which is not included in the total heating surface of 1667 square feet stated in the table appended; through these tubes and also round the steam chamber the heated gases from the smokebox pass back to the chimney B for drying the steam. The chimney B is laid horizontally, in continuation of the annular space which surrounds the steam chamber A, since the great elevation of the boiler, nearly 8 feet from the rails to the centre of the barrel, prevents the chimney being placed vertically with sufficient length.

This heavy-gradient locomotive has eight wheels, 3 feet 6 inches diameter, all coupled, on a base 12 feet 6 inches long; and two cylinders, 18·9 inches diameter and 18·9 inches stroke. It has 28 square feet of grate, and a total heating surface of 1667 square feet, having 356 tubes of $1\frac{9}{16}$ inch diameter. The engine weighs in working order $42\frac{3}{4}$ tons, equally distributed, giving 10 to 11 tons load on each pair of wheels.

A drawing was also exhibited of the Passenger Tank engines for heavy gradients working on the Northern Railway of France, in which the ordinary coupling of wheels is dispensed with, and four $14\frac{1}{4}$ inch cylinders with $13\frac{3}{8}$ inches stroke and 5 ft. 3 ins. wheels on two independent axles are employed. One pair of cylinders and wheels is placed at each end of the engine, with small intermediate carrying wheels 3 feet 6 inches diameter, on a wheel base of 17 feet total length.

A second drawing was shown of the four-cylinder Goods Tank engines employed on the same railway, with six pair of wheels 3 feet 6 inches diameter, coupled in two sets of three, each pair of cylinders working three pairs of coupled wheels: the wheel base is 19 feet 8 inches long, and the fore and hind axleboxes have $1\frac{1}{4}$ inch play transversely to admit of running round quick curves of 600 feet radius. The cylinders are $16\frac{1}{2}$ inches diameter with $17\frac{1}{4}$ inches stroke, and the boiler contains 464 tubes $1\frac{9}{16}$ inch diameter. The weight of the engine is 41 tons empty, and 57 tons full, equally distributed, giving 9 to 10 tons on each pair of wheels.

In the "Dromadaire" and the two other kinds of engine exhibited in drawings by the Northern Railway, the cylinders are outside, and the valve gearing outside them and overhung, which is, as already remarked, the most unfavourable position of gearing for continued accuracy of working. The weight of these engines is top-heavy; and for a run of 230 miles, the length of the line, they cannot well be worked with safety at the occasional high speeds demanded by a large traffic on a long line. The calculations of the capacity of the engines have been based on heating surface as such, which has been assumed to be synonymous with evaporative power. It must be remarked however that there is only ·44 inch clear space between the 356 tubes of the "Dromadaire," and only ·56 inch between the 464 tubes of the four-cylinder goods engine: proportions utterly inadequate to maintain an effective circulation and evaporating action on every unit of surface. There can be no doubt that half the number of tubes properly placed would have answered the purpose decidedly better. The best thing about these engines is the uniform distribution of the weight, giving great tractive power without distressing the road on the straight portions; but the wheel base is impracticably long in the four-cylinder engines, and must greatly strain the engine and road as well as add to the resistance on sharp curves. The proportion of the tractive power, taking the effective mean pressure in the cylinders at 80 per cent. of the boiler pressure for low speeds, is about one sixth of the weight for adhesion; which is a fair proportion and utilises the immense weight of the engine.

The designs of an "articulated" Tank locomotive of great power, like what is known in England as a bogie engine, are exhibited in the French department by Messrs. Meyer of Vienna, one of whom is the inventor of the well known variable expansion gear. On many railways an adhesion weight of 40 tons has now become insufficient, and the necessity for constructing railways cheaply has led to the adoption of steep gradients and quick curves; so that the engines adapted to work these lines must have in certain cases 50, 60, and even 80 tons adhesion weight, with the means of bending or fitting the engine to the curves, since the practice of using assistant engines or separating the trains into two or more parts in particular situations is objected to as inconvenient and costly. This engine has a single long boiler of large dimensions, as shown in the side elevation, Fig. 8, Plate 24, mounted on two separate carriages, with a swivelling connexion, each having its own separate pair of cylinders working six coupled wheels placed near together; so that the engine, although of great total length, could readily pass round very sharp curves, whilst the whole of the weight is made available for driving adhesion.

The boiler rests on the front bogie frame by a hollow ball-and-socket pivot C at the centre over the middle axle, as seen in the longitudinal section, Fig. 9, Plate 24, and the sectional plan, Fig. 10, Plate 25; and on the back bogie frame by two hemispherical bearings DD on the frame, one on each side of the firebox, as seen in the side elevation, Fig. 8, and the plan, Fig. 10. The boiler thus rests on three points, whilst the two bogie frames are each free to follow the curves and irregularities of the road by swivelling under the boiler, as shown by the second plan, Fig. 11, which represents the engine on a sharp curve, the centre line of the boiler being indicated by the strong dotted line E. The hemispherical bearings DD at the sides of the firebox have a limited play, sliding fore and aft to suit the changing position of the boiler relatively to the hind bogie frame. The middle pair of wheels in each bogie have a considerable amount of transverse play allowed them, so as to move laterally in running round sharp curves, as seen in the plan, Fig. 11. The two bogie frames are connected by a single strong coupling rod F, having spherical bearings at each end.

The whole of the cylinders, valves, and other mechanism is outside the wheels. The steam from the boiler is conveyed to the two pairs of cylinders by the connecting pipes G with flexible joints, shown in the side elevation, Fig. 8, and transverse section, Fig. 12; and the exhaust steam from both pairs of cylinders is carried up into the smokebox by the exhaust pipe H through the centre of the hollow pivot C, Fig. 9, the exhaust from the hind bogie communicating with that of the front by means of the flexible connexion I, Figs. 9 and 11.

The distribution of weight on the two bogie frames is such that the centre of gravity of each of the two portions of the load is at the centre axle. The water tanks JJ are in front, and the coal boxes K behind, Figs. 8 and 9, Plate 24. The total weight of 60 tons is available for adhesion, 10 tons on each axle. Each bogie frame stands on a wheel base of 8 feet 6 inches, and the centres of the two bogies are 22 feet apart. The wheels are 3 feet 10 inches diameter, and the cylinders 17½ inches diameter with 19¾ inches stroke. The tractive power is estimated at 22000 lbs., nearly one sixth of the weight, so as to take a gross weight of 2300 tons including the engine at 10 miles an hour on a level; and 340 tons up an incline of 1 in 40 or 155 tons up 1 in 17 at the same speed.

This plan of locomotive affords in the writer's opinion the most satisfactory solution yet given of the problem of obtaining a goods engine of maximum power. With independent bogie frames, each having its own separate pair of steam cylinders, a mass of coupling rods and parallel motions is got rid of, and the resistance of the engine is materially reduced in its working parts and in passing along curves, leaving an important balance of power for useful work.

In the Belgian department is one six-wheel-coupled inside cylinder Goods engine for the Belgian State Railway, made and exhibited by the Société Anonyme de Couillet. This engine is shown in side elevation in Fig. 13, Plate 26. The firebox, shown in longitudinal section in Fig. 14, is a reproduction of the English one previously described in the Chatham and Dover engine, with a long inclined grate, but without the longitudinal water partition. This firebox affords the same advantage in admitting the hind axle below it, giving a moderate

wheel base, in this instance 13 feet 1 inch; and equalising the distribution of the weight on the wheels, the loads being as follows :—

Leading wheels . . .	11·00	tons.
Middle wheels . . .	11·45	„
Trailing wheels . . .	11·00	„
Total weight .	33·45	„

The connexion of the machinery and framing in this engine is in the writer's opinion radically wrong. The three axles each have two outside bearings, carried by two single outside frame plates; and the cranked axle has only one additional bearing 4¼ inches long, placed in the centre between the cranks. This single narrow bearing compressed between the two cranks must receive the entire fore and aft strain of the steam pressure; whilst the outside bearings more than 6 feet apart are 7 inches long, and can receive very little of the fore and aft thrust and pull while the middle bearing is new. But as the middle bearing must prematurely wear loose, the greater part of this strain will then be thrown upon the outer bearings 6 feet apart; and this, acting in addition to the strain arising from the loads on the bearings outside, will be likely to break the axle. Again the fastening of the cylinders to the frame is effected through the valve chests, which are exterior to the cylinders, in two castings spanning the space of 6 feet between the frame plates: an arrangement which, unless the cylinder castings are made exceedingly strong and heavy, will likewise overstrain and break the connexions. On the other hand by devoting to the valve gear and eccentrics the space on the cranked axle that is usually occupied by the inside bearings, the valve motion is very conveniently accommodated; and probably this slight advantage was the inducement to depart from the usual and indispensable application of inside bearings at the wheels.

The Austrian State Railway exhibited a Passenger Express engine, the "Duplex," shown in Figs. 15 and 16, Plates 27 and 28, having four cylinders and four cranks on a single driving axle, specially designed for steady running at high speeds. The usual counterweights in the driving wheels are here superseded and the reciprocating and working parts are made to balance each other by placing a pair of outside

cylinders L L side by side and connecting them to a crank and return crank M, Fig. 16, opposed to each other, on each side of the engine; so that the two pistons on each side and all their connexions move in contrary directions and balance each other's inertia. The cylinders LL, shown enlarged in Figs. 17, 18, and 19, are 10⅞ inches diameter, with 24⅞ inches stroke, and 6 ft. 9 ins. driving wheels.

There can be no question that this system is perfectly successful in effecting the object in view; and had it been brought out twenty years ago, it would no doubt have been highly appreciated. But as the balancing of engines with two cylinders has for the last ten years been completely accomplished for all practical purposes by means of counterweights, the use of four cylinders as in this engine is not likely now to become popular; unless indeed railway companies in the race of competition should aim at excessive speeds of 80 or 100 miles an hour.

The Austrian State Railway also exhibited the "Steierdorf," a heavy Tank engine with five coupled axles, shown in side elevation and plan in Figs. 20 and 21, Plates 29 and 30. The boiler rests on two frames coupled together by a pivot bolt N. The steam cylinders L are fixed on the front frame, and the tank J on the hind frame; and the three pairs of wheels of the front frame are coupled to the two pairs of the hind frame by means of an intermediate shaft O and radiating parallel motion P, shown enlarged in the transverse section, Fig. 22, Plate 31. This intermediate shaft O is ingeniously contrived to adapt itself to the varying angularity of the hind frame on curves, and at the same time to continue to transmit the power from the first to the second frame, as shown by the plan, Fig. 23, Plate 31, representing the position of the several coupling rods when the engine is on a curve. The intermediate shaft O has overhung cranks on each end and is carried on spherical bearings by the distance pieces R, Fig. 22, on the front axle S of the hind frame; it is also kept at a constant distance from the hind axle T of the front frame by the distance links U, Fig. 20, having spherical bearings at both ends; and the cranks of the intermediate shaft O are connected to those of the axles S and T by the coupling rods V and P, all of which have spherical bearings at both ends. The relative positions of the three axles being

thus fixed, the power is transmitted from the hind or driving axle T of the front frame, through the coupling rods P to the cranks on the intermediate shaft O, thence by the coupling rods V to the outside cranks on the front axle S of the hind frame, and further by coupling rods to the hindmost axle. The wheels are 3 feet $3\frac{1}{2}$ inches diameter, the cylinders $18\frac{1}{8}$ inches diameter with $24\frac{7}{8}$ inches stroke, and the total weight in working order is 46 tons. The firebox made for burning coke has 15 square feet of grate; and the boiler contains 158 tubes $2\frac{1}{16}$ inches diameter, with ·69 inch clear space between them.

In the Prussian department one engine was exhibited by Mr. A. Borsig of Berlin. It was a six-wheel four-coupled engine, with outside cylinders 17 inches diameter by 22 inches stroke, and driving wheels of 4 feet 6 inches diameter, the hind wheels being coupled, and all the axles being between the firebox and smokebox. This type of engine is exclusively employed on the Minden and Cologne Railway for mixed and goods trains; and also on many other German railways. The free use of steel in the construction of this engine confers on it an air of lightness, perhaps too great lightness, which contrasts strongly with the heaviness of the tender.

The proportions of the boiler are good; and this circumstance, in addition to the very excellent and well finished work, may account for the popularity of that class of engine: but it has some grave defects which must detract from its usefulness. The suspended weight is carried on three points, by a cross spring over the leading axle and compensating or equalising levers connecting the springs of the two driving axles on each side of the engine. This notion of a triangular elastic bearing with the apex in front, much thought of at one time, is now nearly discarded in England, on account of its giving the engine a dangerous freedom of movement at high speeds.

The cylinders are fitted with double valves for variable expansion, the expansion valve being on the back of the other, with a central passage for steam through it: the lower or leading valve is worked by a link motion in the usual manner; and the upper valve by a separate rod from the fore eccentric working in a grooved sector, from which a variable travel and cut-off are communicated to the valve.

The steam port opens for the exhaust at 90 per cent. of the stroke for all degrees of expansion, and is only opened 3-8ths inch for the exhaust when the piston arrives at the end of the stroke; and as the steam ports are very small in area, each being only 1-20th the area of the piston, there can be no doubt the back pressure is very considerable in consequence, and more particularly with an outside cooling cylinder. For a 17¼ inch outside cylinder in the Caledonian engine previously described the area of steam port provided is 1-11th that of the piston, whilst the valve is open full port for the exhaust when the piston reaches the end of the stroke. Moreover it is not good practice to keep the same point of the stroke for the exhaust under all degrees of expansion; high expansive working usually accompanies high speeds, and therefore the exhaust should be made to open earlier in the course of the stroke for the higher grades of cut-off, in order to give the steam greater liberty for escape before the piston returns upon it. These conditions of the good working of steam are comprehended in Stephenson's expansion link motion, and are now thoroughly appreciated and established in English practice; and the other attempts at expansive valve motion for locomotives have been abandoned in this country.

In employing steel for the working parts of this engine, such as the piston rods, the connecting and coupling rods, and the crank pins, the dimensions of the wearing surfaces have in some cases been reduced. The bearings of the coupling rods are reduced in proportion to the size of the rods; though it is reasonable that as the strains remain the same the sizes of the wearing surfaces should not be altered. The axleboxes are of wrought iron.

In the Saxon department a six-wheel four-coupled engine was exhibited by Mr. R. Hartmann of Chemnitz, specially designed to work in mountainous districts. It is in fact a bogie engine, having four coupled wheels 4 feet 6 inches diameter with 21 tons on them for adhesion, and a swivelling truck on Bissell's plan in front with 7 tons load, making a total of 28 tons. The cylinders are 15 inches diameter by 22 inches stroke; and are outside, with outside valve gearing, as is so prevalent a custom on the continent. The framing has two longitudinal

plates 8 inches deep and 1⅛ inch thick, to which the cylinders are fixed, with 16 inches of overhang. This is an excessive overhang upon so narrow a frame plate, and the valve gear being still further overhung the valve hops about at every stroke as the axleboxes wear. Overhung eccentrics for valve gear outside the crank pin never do well for heavy work in consequence of the unsteadiness. The best feature in this engine is the swivelling truck with a triangular frame, which carries the fore part of the engine on one pair of wheels with a limited but sufficient allowance of lateral play, and radiates on a pivot behind it fixed under the boiler. With a flexible wheel base only 11 feet 9 inches long there is no doubt that in this engine and in others of ordinary size the Bissell truck is well adapted for leading round the quickest curves likely to be found in practice.

In the Italian department an inside cylinder six-wheel-coupled locomotive is exhibited from the Pietrarsa Royal Works, Naples, which is a creditable specimen of the old school of locomotive.

General Conclusions.—It appears that the requirements of continental railway traffic have demanded a greater variety of locomotive engines than has been found necessary in this country. Trains there are heavier; speeds are lower; and, more important than all, inclines are steeper. Whilst therefore the marks of progress in English engines are to be found mainly in refinements upon the original types, Foreign engineers have discarded our traditionary types and have originated novelties in every direction. In England engineers have arrived at higher speeds, with more powerful boilers and increased driving or adhesion weight.

The means of satisfactorily balancing the reciprocating and revolving machinery, the want of which was previously the bane of the outside cylinder engine, by counterweighting the wheels and steadying the engine, have been discovered and carried into practice since 1851; so that the outside cylinder engine properly balanced now runs even more steadily than the inside cylinder engine. Outside cylinders have consequently been employed for high speed and other duty with complete success: they have not however been employed for the heaviest work.

The inside cylinder is generally retained for six-wheel-coupled goods engines, and is not likely to give way to the outside cylinder for that class of work, on account of the objectionable construction involved by outside connecting rods combined with outside coupling rods for all the wheels. But for passenger traffic with four coupled wheels, and the lighter traffic of collieries and other private establishments, the outside cylinder is well suited and is extensively applied. It is however to be explained that the advantage of the six-wheel-coupled engine is limited to the old and the comparatively straight lines of railway, on which the destruction of cranked axles is not rapid and the wear and tear of tyres not severe. For lines with the prevailing sharper curves the four-wheel-coupled outside cylinder engine surpasses in efficiency and economy the six-wheel-coupled engine, running on curves with greater facility, utilising the adhesion weight better, and being subject to less wear. Hence the six-wheel-coupled engine with inside cylinders is to be found chiefly on the older and straighter lines. On the contrary the outside cylinders and the single and four-coupled driving wheels are to be found generally on the newer lines that have many quick curves.

In England the use of more than six coupled wheels in one engine has been avoided; three wheels coupled in one line are found sufficiently powerful and sufficiently troublesome, and it is preferred to supplement the power when necessary with an additional engine. On the continent however great efforts have been made to construct an efficient engine with great tractive force and enormous weight for adhesion, to ascend long and heavy inclines peculiar to mountainous districts. The subdivision and disposition of the weight in moderate loads on the rails has been effected with ease by distributing it over a sufficient number of wheels and axles. But the most important part of the problem has been to reconcile the unavoidable extension of wheel base in a straight line with the excessive curvature of the railways; for naturally, though unfortunately, heavy gradients and quick curves are generally to be found in company.

The system adopted on the Northern Railway of France, as shown in the side elevation of the "Dromadaire," Fig. 5, Plate 22, must

fail to answer these requirements; for with a wheel base so extended the resistance of the engine itself must absorb a great proportion of the tractive power. A flexible wheel base is indispensable, and two ordinary engines connected together would work much more efficiently and economically than the vast masses actually employed. The opinion on the Northern Railway of France against the use of coupling rods in passenger engines, and the consequent substitution of two independent pairs of driving wheels with independent cylinders, must appear to be erroneous. The truth is that for working four driving wheels one pair of cylinders with coupling rods is the best method of providing adhesion weight; more especially since by the use of steel for the tyres their excessive and unequal wear and the consequent straining of the coupling rods are to a great extent prevented: at all events the wear of the tyres may be regulated and equalised, which removes the only objection worth consideration.

The Austrian plan of coupling over an extensive wheel base by a self-acting radial adjustment in the "Steierdorf," Plates 29, 30, and 31, is decidedly a better plan, and merits a thorough trial. There is nevertheless a complication of mechanism with many rubbing surfaces, liable to occasional overstraining, from irregular play of the bearings arising in wear in transmitting the power over a long distance through a flexible connexion; and engineers have to look in another direction for a comprehensive and satisfactory solution of the problem.

The plan of Meyer's engine appears in the writer's opinion to be the best yet brought forward for distributing steam power over a flexible train of coupled wheels, as shown in Plates 24 and 25. It is based on sound principles, as experience will no doubt prove. It is known that practically a locomotive boiler with ordinary management delivers a better supply of steam to a given pair of cylinders fully worked at a low speed of piston than at a high speed: the steam blows off from the boiler, and there is plenty to spare. By making the boiler a little larger therefore it is justly reckoned that steam can be supplied for four cylinders at a low speed, as well as for two; and the train of wheels is therefore divided into two independent groups under the boiler, each group free to adapt itself to the line of rails, and fitted

with its own pair of cylinders and the necessary coupling rods, and receiving a separate supply of steam from the boiler. In short two steam bogies are employed, which carry the boiler and its accessories just as a load of timber is carried on a couple of swivelling trucks.

The abstract importance of heating surface appears to have been overrated, particularly by foreign engineers; and the primary importance of free passage for the currents of water in intimate contact with the heating surface, whether of the firebox or of the tubes, has been neglected. The width of the water spaces around the firebox has frequently been reduced to a minimum barely sufficient to preserve the plates from being overheated. The tubes have also been placed so near to one another and in such large numbers as totally to defeat their object of increasing the steam producing power of the boiler, because they have rendered it impossible for the water, crowded with globules of steam, to reach the surface of each tube and become evaporated. Tube surface under such circumstances is ineffective, and ultimately becomes mischievous; for the sediment deposited by water in boilers will, if not scoured out, coat the tubes and block up the spaces between them altogether. The greatest number of tubes known to have been applied in England is the 305 tubes of the Great Western express engine exhibited in 1851. In this engine the tubes, 2 inches in diameter, are placed only ·50 inch apart, and are not so effective for evaporation as the tubes of some of the earlier engines on that line, which were fewer in number but placed at from ·62 to 1·00 inch clear distance apart. In the English engines exhibited in 1862 the greatest number of tubes was 215 in Messrs. Beyer Peacock and Co.'s engine for the Portuguese gauge, with ·56 inch clearance; and 214 tubes in the North Western inside cylinder engine with ·50 inch clearance.

The best English practice exhibited in reference to the tubes is in the writer's opinion to be found in the North Western outside cylinder engine, the Caledonian, and the Great Eastern engines, all of which singularly enough have identically the same proportions; 192 tubes of $1\frac{7}{8}$ inch diameter with ·62 inch clearance, placed in a barrel 3 feet 10 inches inside diameter. The excellence of these proportions is

confirmed by the very satisfactory performances of the engines under very different circumstances.

The greatest number of tubes exhibited in the Foreign engines is 356 tubes with ·44 inch clearance, in the "Dromadaire" class of engines on the Northern Railway of France with the 4 ft. 8½ ins. gauge. The drawings of the twelve-wheeled four-cylinder goods engines employed on the same railway show 464 tubes with ·56 inch clearance; but these proportions will undoubtedly disappoint the expectations of the projectors, and the experience of a few years will, it is presumed, correct these abstract ideas.

The distinction between fireboxes for burning coal and those for burning coal-slack should not be overlooked. For coal 13 to 15 square feet of grate is sufficient; but for slack the North Western inside cylinder engine has 26 square feet of grate, and the Chatham and Dover engine 27½ square feet. The difference of fuel leads to a difference of treatment, inasmuch as special provision is made for the admission of air above the fuel for burning coal in pieces, in addition to the air that passes through the grate. For coal-slack no such provision is made; the layer of fresh fuel is thin, and a sufficient quantity of air is drawn through the large surface of grate. At the same time the slack is supplied in small quantities, and much more frequently than coal in pieces.

In placing the machinery on the frame it must be remarked that the foreign engineers seem to have merely shown how an inferior arrangement can be made to do. Next to excessive amount of heating surface their partiality is remarkable for overhung valve gearing upon outside cylinders, which is undoubtedly the worst possible position for efficiency and handiness of the engines.

Giffard's injectors have been extensively employed as a substitute for the ordinary feed pumps; and their general adoption in locomotive engines both in England and on the continent is an evidence of their popularity and general efficiency. The only apparent objection to the use of the injector is its inability to deliver heated water at a temperature of more than 120 degrees Fahr.; this prevents the use of means for heating the feed water by the contact or mixture of

Locomotives in International Exhibition 1862.

Name of Maker.	Name of Railway.	Description of Engine.	Total number of Wheels.	Gauge of Rails.	Firebox. Fuel used.	Firebox. Area of Grate.	Firebox. Heating Surface.	Tubes. Number.	Tubes. Outside Diam.	Tubes. Clear space between.	Tubes. Length.	Tubes. Heating Surface.	Total Heating Surface.
				Ft. Ins.		Sq. ft.	Sq. ft.	No.	Ins.	In.	Ft. Ins.	Sq. ft.	Sq. ft.
L. & North Western Ry. Co.	L. & N. Western	Pass. Exp. (in. cyl.), single	6	4 8½	Slack	26·0	242	214	1·87	·50	9 4	980	1222
Do. do. ...	Do. do. ...	Do. (out. cyl.), do.	6	4 8½	Coal	14·9	85	192	1·87	·62	10 9	1013	1098
Beyer Peacock & Co.	S. East. Portugal	Passenger Express, do.	6	5 5¾	Coal	18·0	101	215	2·00	·56	10 11	1238	1339
Neilson & Co.	Caledonian	Do. do. do.	6	4 8½	Coal	13·9	89	192	1·87	·62	11 5	1080	1169
Sharp Stewart & Co.	L. Chat. & Dover	Goods, six coupled	6	4 8½	Slack	27·5	120	189	2·00	·62	10 10	1072	1192
W. Fairbairn & Sons	Midland	Do. do.	6	4 8½	Coal	14·5	84	180	2·00	·62	11 9	1107	1191
Sir W. G. Armstrong & Co.	East Indian......	Mixed, four coupled	6	5 6	Coal	17·0	97	157	2·25	·56	10 11	1009	1106
R. Stephenson & Co.	Great Eastern ...	Do. do.	6	4 8½	Coal	13·5	72	192	1·87	·62	11 8	1105	1177
G. England & Co.	....	Mixed Tank, do.	6	4 8½	Coke	8·5	55	153	1·75	·50	8 5	645	700
Manning Wardle & Co. ...	....	Small Tank. do.	4	4 8½	Coal	4·9	30	55	2·00	·69	7 5	218	248
Neath Abbey Iron Co. ...	....	Colliery Tank, do.	4	2 8	Coal	3·5	37	59	1·50	·62	6 0	144	181
Orleans Railway Co.	Orleans	Passenger, single	6	4 8½	Coal	...	96	179	...	...	...	1046	1142
Cail & Co., Paris...........	Do.	Goods, six coupled	6	4 8½	Coke	14·6	88	187	2·06	...	14 5	1263	1351
Northern of France Ry. Co.	North. of France	Heavy Tank, eight coupl.	8	4 8½	Slack	28·2	109	356	1·56	·44	11 5	1558	1667
Société de Couillet	Belgian State ...	Goods, six coupled	6	4 8½	Slack	28·0	110	225	1·75	·62	11 6	1192	1302
Austrian State Ry. Co. ...	Austrian State...	Passenger Express, single	6	4 8½	Coke	15·0	84	160	2·06	·62	14 6	1260	1344
Do. do. ...	Do. do. ...	Heavy Tank, ten coupled	10	4 8½	Coke	15·0	78	158	2·06	·69	14 6	1245	1323
A. Borsig, Berlin............	Minden & Coln.	Mixed, four coupled	6	4 8½	...	11·6	65	156	1·94	...	13 9	960	1025
R. Hartmann, Chemnitz	....	Do. do.	6	4 8½	...	11·5	70	148	...	...	...	790	860

Locomotives in International Exhibition 1862.

Name of Maker.	Cylinders.			Diameter of Driving Wheels.	Diameter of Blast Orifice.	Steam Pressure in boiler.	Height of centre of boiler above rails.	Length of Wheel base.	Weight of Engine Empty.				Weight of Engine in Working Order.			
	Inside or Outside.	Diam.	Stroke.						Leading wheels.	Middle wheels.	Trailing wheels.	Total Weight.	Leading wheels.	Middle wheels.	Trailing wheels.	Total Weight.
		Ins.	Ins.	Ft. Ins.	Ins.	Lbs.	Ft. Ins.	Ft. Ins.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
L. & North Western Ry. Co.	In.	18	24	7 6	5·25	150	7 5	18 0	10·60	13·30	7·30	31·20	11·90	14·30	8·50	34·70
Do. do. ...	Out.	16	24	7 7½	4·50	120	6 .6	15 5	9·60	8·00	6·40	24·00	9·40	11·50	6·10	27·00
Beyer Peacock & Co.	In.	16	22	7 0	4·50	120	7 1	15 4	8·50	10·70	6·30	25·50	9·20	11·60	7·50	28·30
Neilson & Co.	Out.	17¼	24	8 2	5·50	120	6 6	15 8	...	...	...	27·25	9·25	14·55	6·85	30·65
Sharp Stewart & Co.	In.	17	24	5 0	4·87	120	6 4	15 6	9·35	10·70	8·55	28·60	10·65	11·55	9·85	32·05
W. Fairbairn & Sons	In.	16	24	5 2	4·25	140	6 5	16 6	11·80	8·85	7·80	28·45	12·30	11·25	8·70	32·25
Sir W. G. Armstrong & Co.	Out.	16	22	5 7	4·50	120	6 8	15 4	10·63	11·06	7·96	29·65	11·47	12·55	8·67	32·69
R. Stephenson & Co.	Out.	17	24	6 1	4·50	110	5 10	15 1	10·00	10·05	9·40	29·45	11·10	10·70	10·05	31·85
G. England & Co.	Out.	11	17	4 0	3·50	120	5 3	10 0	...	...	...	15·00	...	...	...	17·00
Manning Wardle & Co. ...	Out.	9	14	2 9	2·62	120	4 0	4 9	...	—	...	8·75	...	—	...	10·25
Neath Abbey Iron Co. ...	Out.	8	16	2 4	2·00	80	1 11	4 0	2·82	—	2·98	5·80	3·27	—	3·58	6·85
Orleans Railway Co.	Out.	15·75	25·50	6 7¾	...	...	...	14 1	9·50	11·45	4·50	25·45	10·65	12·50	5·35	28·50
Cail & Co., Paris	In.	18·00	26·00	5 0	...	120	...	11 4	...	...	...	...	...	...	...	...
Northern of France Ry. Co.	Out.	18·90	18·90	3 6	...	118	7 8	12 6	...	...	...	31·23	10·44	{10·64, 10·54}	11·04	42·66
Société de Couillet	In.	17·60	23·50	4 9	variable	...	6 5	13 1	...	...	...	...	11·00	11·45	11·00	33·45
Austrian State Ry. Co. ...	Out.	10·87	24·87	6 9	variable	...	...	11 5	...	...	...	...	9·84	9·54	12·30	31·68
Do. do. ...	Out.	18·12	24·87	3 3½	variable	...	...	19 3	...	...	...	...	9·15	{8·27, 9·69}	{6·79, 12·11}	46·01
A. Borsig, Berlin...........	Out.	17·00	22·00	4 6	...	100	...	11 0	...	...	...	...	8·00	12·00	12·00	32·00
R. Hartmann, Chemnitz	Out.	15·00	22·00	4 6	...	...	...	11 9	...	...	...	...	7·00	10·50	10·50	28·00

the water with the exhaust steam: but the injector may be used with surface heaters, in which the water whilst on its way to the boiler may be heated after it has passed through the injector, by contact with steam-heated surfaces.

The CHAIRMAN remarked that the locomotive engines formed an important and interesting feature of the Exhibition, and the paper just read contained a valuable summary of the principal varieties of construction presented by them. The improvements effected since 1851 were perhaps not very striking to a casual observer, except in the important change from coke to coal, in which respect certainly a very great improvement had been made during the past eleven years, causing a large saving in consumption of fuel; and other valuable improvements in working had also been carried out. He asked what were the comparative results of different engines in economy of fuel.

Mr. CLARK replied that the question of the comparative value of the firebox and of the tubes as heating surface, to which he had referred, was one requiring particular attention: and he thought the two London and North Western engines exhibited furnished valuable information upon this subject. The performance of the inside cylinder engine with 242 square feet of heating surface in the firebox was not so good in work done per lb. of coal as that of the outside cylinder engine with only one third that extent of heating surface in the firebox but rather more in the tubes.

The CHAIRMAN enquired how many of the water troughs there were now in use, for enabling the engines to take up a supply of water into the tender whilst running, as described in the paper.

Mr. F. W. WEBB replied that there were now three pairs of troughs on the London and North Western Railway: one near Conway, another at Parkside on the Liverpool and Manchester line,

and the third near Wolverton. They were all working with complete success, and no difficulty was ever experienced in taking up the required supply of water at any speed above 15 miles an hour. The trough at Parkside was used for the heavy through goods trains, which were now enabled to run through without stopping, avoiding the serious obstruction of the line previously caused by their having to stop for water; and the troughs at Conway and Wolverton were used for the express and mail trains. An engine had on one occasion run through with a train from Holyhead to Stafford without stopping, a distance of 130½ miles, by means of picking up water from the trough at Conway; that was the longest run that had ever been made yet without stopping.

The Chairman enquired what were the steepest inclines worked by locomotive engines, and how much weight the engine could take up in such cases.

Mr. Clark said the steepest gradient worked by locomotives that he had heard of was 1 in 17 on the Mountain Top Incline of the Virginia Central Railway, which was stated to have been worked safely by locomotive engines for several years with no accident. On some of the continental railways also there were inclines of 1 in 20 worked by locomotives, and when properly managed the engine could be made to take up them nearly as much as its own weight of train, but then every artificial help was required to increase the adhesion. On the American lines he understood chalk was sometimes used to increase the bite of the wheels, or else ordinary sandboxes; and in some places the curves were so sharp that oil was employed to lubricate the flanges of the leading wheels. On the Giovi Incline of 1 in 29 on the Sardinian Railway two four-wheeled tank engines were employed, coupled together tail to tail with the enginedriver between them; but this arrangement involved two complete engines with separate boilers and machinery, besides the extra trouble of working two boilers instead of one: and he therefore thought Messrs. Meyer's plan of a single large boiler mounted on a swivelling frame was superior in respect of simplicity and diminution of first cost, and a principal point in this engine was the swivelling connexion of the frame for carrying the long boiler.

Mr. W. BOUCH enquired how the steam communications to the two pairs of cylinders were managed in that engine so as to allow of the frame swivelling: he thought any arrangement of flexible tubes for the purpose must be a source of much trouble in practice. No doubt a connexion between the engine and tender for driving the tender wheels was desirable for obtaining the benefit of the additional adhesion; but the difficulty in all such cases was the additional complication involved.

Mr. CLARK said the communication from the boiler to the cylinders on a swivelling frame must certainly be a delicate point, and he thought the ball-and-socket coupling such as was used in ordinary tender feed-pipe connexions was decidedly superior to any plan of tubes with flexible india-rubber joints.

The CHAIRMAN enquired whether any of the locomotives exhibited had iron fireboxes or iron tubes, or whether they had all copper fire-boxes and brass tubes, as in the ordinary English engines. He had heard much diversity of opinion as to the comparative value of brass and iron tubes, for though the difference in first cost was so great, the difference in the wear and tear and in disposing of the old materials when worn out was said to make the actual economy about the same in both cases.

Mr. CLARK replied that there were no iron fireboxes or iron tubes in the locomotives exhibited; but the Prussian engine built by Borsig of Berlin had fireboxes made of homogeneous steel, and also tubes of the same material. The other foreign locomotives had all brass tubes, and he believed it was now almost the universal practice to use brass tubes, as these were found so much more durable in locomotives than iron.

Mr. J. FERNIE remarked that on the English lines brass tubes were the only ones that were found to stand well, and he knew of no large line on which iron tubes were used. With regard to the various arrangements of large engines that had been described for working heavy inclines, he thought they would not apply to this country, as there were scarcely any English lines requiring anything beyond a large size six-wheel-coupled engine. They had on the Midland Railway the steepest incline worked by locomotives on a main

line in this country, the Lickey Incline of 1 in 37, which was worked by a large six-wheel-coupled tank engine, the wheels being 4 feet diameter, and the cylinders 16½ inches diameter with 2 feet stroke; the weight on each pair of wheels for driving adhesion was about 12 tons in this case. In reference to the dimension of the water spaces between the boiler tubes in the locomotives exhibited, and the disposition of the frames and the weights upon the several pairs of wheels, there might be room for considerable difference of opinion from the views expressed in the paper; but he considered they were greatly indebted for the valuable information which the paper afforded on so extensive and important a subject.

The CHAIRMAN proposed a vote of thanks to Mr. Clark for his paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

4 AND 5 AUGUST, 1863.

The ANNUAL PROVINCIAL MEETING of the Members was held in the Concert Room, St. George's Hall, Liverpool, on Tuesday, 4th August, 1863; WILLIAM CLAY, Esq., Chairman of the Local Committee, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The CHAIRMAN announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

JOHN ARMSTRONG,	Sunderland.
ARTHUR BUTLER,	Surdah, Bengal.
ANDREW CRAIG,	Birkenhead.
ISAAC HARTAS,	Rosedale.
ROGER HIND,	Warrington.
WALTER STUART HUTTON,	Leeds.
EDWARD A. JEFFREYS,	Low Moor.
BRYAN JOHNSON,	Chester.
EVAN LEIGH,	Manchester.
EDWARD R. LLOYD,	Birmingham.
WILLIAM MUIR,	Manchester.
EDWIN RICHARDS,	Pontypool.
EDWARD TOMLINSON,	Manchester.
WILLIAM TOWNSEND,	Coventry.
PETER WRIGHT,	Dudley.

HONORARY MEMBERS.

William Brockbank, ...	Manchester.
William Butler, ...	Cadiz, Spain.
John Fisher, ...	Dudley.
John Woolley, ...	Ripley.

The following paper was then read:—

ON THE CONSTRUCTION OF IRON SHIPS.

By Mr. JOHN VERNON, of Liverpool.

The extended and increasing use of Iron Ships at the present day, after the lapse of about thirty years since they were first fairly introduced, renders their construction a subject of importance in a commercial point of view, and of deep interest to all concerned in the development of science as connected with iron structures generally. The application of iron in place of wood to the structure of ships has necessitated a more careful use of the material employed, and a more correct and perfect application of the mechanical principles that are involved in the construction. It is not intended in the present paper to describe novelties of construction in iron ships, so much as to investigate the present systems that are most approved and practised; and when the great difference is considered between a proper and an improper use of the material employed, and the important results that depend upon it, the advantages of such an investigation become evident.

The rapid rate of increase in the application of iron for the construction of ships is strikingly illustrated by the following facts. In the year 1851 there were built and registered in the United Kingdom 55 iron sailing ships and steamers of a gross tonnage of 15,826 tons; while in the year 1862 the number had increased to 219 vessels and 106,497 tons. In the same years the number of vessels built of timber was as follows: in 1851 there were 617 vessels of a gross tonnage of 133,811 tons, while in 1862 the number of vessels was 740 and the gross tonnage 115,955 tons. It is thus seen that during this period of eleven years there was an increase of 570 per cent. in the tonnage of iron vessels, but a decrease of 13 per cent. in the tonnage of wood vessels; which is the more

remarkable from the fact that less than twenty years ago it was considered by many persons of great experience to be a matter of doubt whether iron ships could be adopted at all for general service with any advantage. This doubt however was not shared in by many thoughtful mechanical men, who were strongly impressed with the advantages to be obtained from the introduction of iron; and the correctness of their views is now thoroughly established by the practical results that have been obtained on such an extensive scale.

The first consideration in the order of the subject will be the main points of superiority of iron ships over those built of wood. These consist in the superior strength, greater durability and less cost of iron ships, together with their larger carrying capability, greater facility of construction, and the more certain supply of the material.

The greater strength of iron ships is shown in daily practice in numerous ways; and it is also shown by the fact that in many modern wood ships it has been found desirable to introduce the use of iron for bulkheads, beams and stringers, and even for the framework itself of the whole structure. But this arrangement it is considered falls very far short in point of strength of a vessel built entirely of iron; and the only ground upon which such a mixed kind of structure can be advocated is the freedom from fouling possessed by wood vessels when they are coppered, which is an advantage existing in the mixed structure on account of the shell portion being of wood.

The greater comparative durability of iron for the construction of ships arises mainly from its freedom from the decay to which wood is always liable in consequence of its being unavoidably subject to constant and extreme variations of temperature and moisture. Another important source of this greater durability is to be found in the firm and substantial union of the several parts of an iron ship by means of rivetting, which effectually prevents that "working" under heavy strains to which all wood ships are more or less liable.

In reference to the question of cost, the comparison in order to be fairly drawn has to be made between the highest class of wood ships as built in this country, with frames of British oak and the

bottom coppered, and the highest class of iron ships. The difference in favour of the latter is in that case about £3 per ton measurement or about 14 per cent.

The larger carrying capability of the iron ship arises first from the reduced weight of the structure, and secondly from the increased internal capacity with the same external dimensions and model as the wood ship. This is shown by the following figures of comparison of a 1200 ton ship of the two constructions. First as to weight. The wood ship with rigging and all outfit weighs say 18 cwts. per ton measure, equal to 1080 tons for the whole ship. The iron ship completed in a similar way weighs only say 15 cwts. per ton measure, which would be equal to 900 tons for the whole ship. Hence the 1200 ton iron ship will carry at the same draft 180 tons additional dead weight of cargo; and this will be equal to 11 per cent. addition upon the whole weight of 1600 tons which is actually carried by a nominal 1200 ton wood ship: or if no greater weight be carried, the iron vessel will float at 13 inches less draft of water. Secondly as to capacity. The wood ship has an internal capacity of 93,343 cubic feet, or at 100 feet per ton 933 tons. The iron ship, because of the reduced thickness of the sides and bottom of the hull, has a capacity of 1108 tons. Hence in regard to capacity the gain of the iron ship is 175 tons or about 19 per cent. over the wood ship; and there will consequently be space enough to contain the increased weight of 11 per cent. which the iron ship is capable of carrying by reason of its lighter hull.

As to facility of construction it may be remarked that, instead of a long period being required for preparation and seasoning of the material, as is necessary for a wood ship, the material for the iron ship can on the other hand be used immediately after it is manufactured. Also wood can only be had just as it has grown by nature, and it has to be converted to the purposes required, mostly by hand labour; but the iron can at once be obtained of the precise sizes and forms required, and the use of machinery can be very largely adopted in working it up in the structure of the ship, whereby a great amount of economy can be effected, both in the time occupied and in the cost of labour.

The next point to be considered is the actual strength of an iron ship and its capability of bearing strain; and whether the distribution of material is judicious and efficient, considering the strains to which it is subjected. For this purpose the case will be taken of a ship of 1200 tons, as shown in side elevation in Figs. 1 and 2, Plate 32, the dimensions of which are 205 feet length, 34½ feet beam, and 23 feet depth of hold; and the ship is supposed to be built to class A 1 at Lloyds' for 12 years or for 20 years with the Liverpool Underwriters' Association, which is considered the best construction at the present day. The transverse section of such a ship is shown to a larger scale in Fig. 3, Plate 33, the section of the iron being shown black; and the sectional area of iron is as follows:—

	Fig. 3.	Sq. Ins.
Stringer plates, tie plates, and angle irons on main deck	A	77
Do. do. do. on lower deck	B	55
Sheer strakes	C	61
Sides down to top of bilge	D	298
Turn of bilges and flat of bottom	E	379
Garboard strakes	F	59
Middle keelson	G	42
Sister keelsons	H	43
Bilge keelsons	I	20
Lower hold stringers	K	41
Keel piece	L	26
Total		1101

In the above sectional area the deck planks, amounting to 1770 square inches, have been excluded from the calculation, because although aiding considerably when in compression they are of very little value for tension; and both cases have to be taken into account.

Taking first the extreme case of strain upon the vessel when supported only at the ends, and allowing 10 feet length at each end for the support, the ship will be as shown in the diagram, Fig. 1, Plate 32, with a length of 185 feet between the supports: in this case the bottom of the vessel is in tension and the top in compression. The displacement of such a vessel at her loaded draft of 20 feet is 2703 tons, and this weight is made up as follows:—

		Tons.
Iron in hull for 1166 tons measurement, at 10½ cwts. per ton	612	758
Woodwork do. do. at 2½ cwts. per ton	146	
Rigging and outfit	108	
Water and general stores	35	1945
Weight of cargo	1802	
Total		2703

The cargo and other load carried is thus seen to amount to 1945 tons, which load is unequally distributed over the length of the ship in consequence of the larger capacity in the midships as compared with that at the two ends: and the proportionate distribution as measured from actual sections of an existing ship is shown approximately by the figures marked upon the side elevation, Fig. 1. The length unsupported being divided into six equal portions, the respective cargo capacities or loads of these are in the proportions of 11, 20, 23, 23, 22, 14 respectively, proceeding from the stern to the bows. The result obtained by taking the mean effect of these several loads at the centre of the vessel is that the strain produced at the centre by the distributed load amounts in this case to 74 per cent. of the total load, instead of 50 per cent. or one half the load as would have been the case if the distribution of the load had been uniform throughout the entire length. Hence the total distributed load carried being 1945 tons, as ascertained above, the equivalent centre load will be in this case 74 per cent. of that amount or 1440 tons; and the additional weight of the vessel itself, 758 tons, may be considered as equivalent to a load of one half the amount or 379 tons at the centre; making together a total load at the centre of 1819 tons, one half of which or 909 tons is acting at each end by tension on the lower part of the vessel, with a leverage of 92½ feet, or half the length of the unsupported portion of the vessel.

As the form in which the material is placed in the sectional area of the ship is necessarily determined by the carrying and floating requirements of the ship, and is consequently not free to be arranged in the manner that would simply give the greatest strength as a girder, this case does not admit of satisfactory comparison with a wrought iron box-girder for calculation of the transverse strength. It may be convenient consequently to consider the strains on the whole sectional area as if acting upon a solid girder composed of the material that

exists at each point in the depth of the vessel, concentrated into a solid girder of the same sectional area and depth. The diagram, Fig. 4, Plate 33, shows the total sectional area of the vessel drawn to double the scale of Fig. 3 in area, or 1-5000th of the actual area of section. The metal is here condensed into the form of a flanged girder for comparison of the areas of resistance in the several portions, in order to deduce an approximate neutral axis for the whole section; and the positions of the several portions of the girder are made to correspond with the exact positions in the general section of the vessel itself, Fig. 3. The sectional areas of iron at the main deck, lower deck, and bottom are 113, 55, and 493 square inches respectively. The top flange of 113 square inches area is made up of the main deck plates and angle irons A of 77 square inches, and 36 square inches of the sheer strakes C from the top M downwards: the bottom flange is taken to include the entire section of iron in the bottom E E of the vessel, from the keel L up to the points O O at turn of bilge on either side, together with the five keelsons G, H H, and I I. The intermediate areas of the sides are 120 square inches between the upper and lower decks, from the sheer strakes C down to the lower deck N; and 320 square inches from the lower deck N down to the point O, at which the bottom is considered to begin: the latter area being divided into two portions of 158 and 162 square inches respectively above and below the neutral axis P P. Then these several areas multiplied into their respective vertical distances or leverages give the upper dotted line P P as the approximate neutral axis, about which the moments of the areas above and below are equal; taking the total compression resistance of the upper portion as 5-6ths of the tensile resistance of the lower portion, since the ultimate strength per square inch of wrought iron to resist compression is 5-6ths of its strength for tension.

In this case the decks being in compression and the 4 and 3 inch planks of which they are composed being fixed tight and solid together, the timber will contribute materially to the strength of the ship. The resistance of the pine wood to compression may be taken at 3 tons per square inch; and the compression strength of wrought iron being 17 tons per square inch or 5-6ths of its tensile strength of 20 tons,

the strength of the wood is about 1-6th that of wrought iron: the value of the timber may therefore be safely taken at 1-8th of the strength of wrought iron per square inch. Hence the sectional area of the main deck planking being 960 square inches, 1-8th of this or 120 square inches has been added in the above calculation to the area of the top flange of the girder in Fig. 4, Plate 33, as shown by the outer lines surrounding the shaded portion, making the total area of the top flange 233 square inches. For the lower deck of 810 square inches sectional area, 1-8th of this or 101 square inches has similarly been added, making a total area of 156 square inches.

The neutral axis P P thus found is situated 9 feet above the centre line of the bottom portion, Figs. 3 and 4, Plate 33; and the strain tending to produce fracture at the centre of the vessel will therefore be 909 tons $\times$ $92\frac{1}{2}$ $\div$ 9 = 9343 tons. Then assuming this strain to be resisted by all the portions in tension in proportion to their respective distances from the neutral axis P, the effective area resisting by tension will be 493 square inches for the bottom portion, and 1-3rd of 162 or 54 square inches for the lower sides; since the centre of gravity of the lower sides, from the neutral axis P down to the point O in Fig. 3, is only a little more than one third of the way down from the neutral axis P to the centre line of the bottom portion, as seen in Fig. 3. Hence the total effective area resisting tension is 547 square inches, on which the above load of 9343 tons gives a strain of 17 tons per square inch upon the iron.

This calculation is on the extreme supposition of the vessel being entirely out of the water and supported only at the two extremities; but practically the vessel when carrying her cargo is supported from end to end by the water, excepting to the extent that this support may be partially withdrawn by the waves and other causes producing an inequality of immersion. It has to be observed that, although the weight of the whole vessel is balanced by its displacement, the extreme ends are very much heavier than their own displacements, and consequently a larger weight is left unsupported at the ends; and the effect of this imperfect support of the ends of the vessel while afloat, inasmuch as it throws a strain of compression on the bottom, will to that extent reduce the strain of tension to which the bottom of

the vessel is exposed in the case now under consideration, when she is supported at the ends only.

Now considering the opposite case of the vessel being supported only at the centre, as shown in Fig. 2, Plate 32, the strains on the vessel will then be reversed: the top will be in tension and the bottom in compression. In this case the effect of the unequal distribution of the load, taken from the same data as before, will be to produce a strain corresponding to a load at the ends of the vessel amounting to only 44 per cent. of the total load, instead of 50 per cent. or one half as would have been the case if the load had been uniformly distributed throughout the entire length. The total distributed load carried being 1945 tons as before, the equivalent load at the ends will in this case be 44 per cent. of that amount, or 856 tons acting at the two ends; and the additional weight of the vessel itself, 758 tons, being taken as before to be equivalent to one half that amount or 379 tons at the two ends, these make together a total load at the two ends of 1235 tons, one half of which or 617 tons is acting at each end by tension on the upper part of the vessel, with a leverage of half the unsupported length of the vessel or 92½ feet as before.

The neutral axis in this case, found in the same manner as before, but omitting from the calculation the sectional area of the decks which are now in tension, is shown by the lower dotted line Q Q, Figs. 3 and 4, Plate 33; it is situated at a depth of 16¼ feet below the centre of the upper portion, or 21 inches below the previous neutral axis P, thus dividing afresh the 320 square inches area of the lower sides from N to O, Fig. 3, into two portions of 181 and 139 square inches respectively above and below the neutral axis Q, as seen in Fig. 4. The strain tending to produce fracture at the centre of the vessel will therefore be 617 tons $\times$ 92½ $\div$ 16¼ = 3512 tons. Then the effective area resisting by tension, found in the same manner as before, will be 113 square inches for the main deck portion, together with ¾ of 120 or 90 square inches for the top sides between the decks, ½ of 55 or 27 square inches for the lower deck portion, and ¼ of 181 or 45 square inches for the sides below the lower deck; making a total effective area of 275 square inches resisting by tension.

Hence the strain produced by the above load of 3512 tons will be 13 tons per square inch upon the iron.

It may be observed that, although this is an extreme case, it is by no means imaginary as regards the strain which a vessel has to bear continually when floating in the water. For the effect of the imperfect support of the ends of the vessel while afloat, which was previously referred to, is to cause a strain on the transverse area of the midship section similar in action to that caused by the vessel being supported in the middle alone, entirely out of the water, and differing only in degree.

As is well known there are many new plans and improvements in the construction of iron vessels that are partly adopted or in contemplation to be used, which might have been referred to in this paper; but the subject of the paper has been confined to an investigation of the strength and efficiency of iron vessels as generally built of the highest class at the present time. In considering however the strength of any new kinds of structures, the same principles are applicable that have been employed in the case now dealt with.

In order to ascertain the comparative strength of iron and wood ships under the two extreme conditions of strain, the same calculation will now be applied to a wood ship of the first class, such as has been previously referred to, and of the same size, 1200 tons; of which a transverse midship section is shown in Fig. 5, Plate 34, drawn to the same scale as the section of the iron ship in Fig. 3. In Fig. 6 is shown as before, condensed into the form of a solid girder, the area of section of the wood ship, drawn to double the scale in area of Fig. 5, or 1-5000th of the actual area of section. The bottom flange of the girder, Fig. 6, is taken to include all the section of material in the bottom of the vessel, from the keel up to the points R R on either side in Fig. 5. The actual areas of each portion of the section are as marked upon the drawing, Fig. 6; namely 1011 and 1074 square inches in the main deck and lower deck portions respectively, exclusive of the decks themselves; 764 square inches in the sides between the upper and lower decks; 1736 square inches in the lower sides from the lower

deck down to the point R where the bottom is considered to begin; and 5216 square inches in the bottom. In these areas the "ceiling" or lining of the hold, being constructed of 4 inch planking secured to the frames of the ship, has been included as acting efficiently both in compression and tension.

When the vessel is supported only at the ends, having the bottom in tension, the main and lower decks, of 944 and 920 square inches area respectively, have to be included in the compression resistance, as in the iron ship; thus the areas of the main and lower deck portions are here increased to 1955 and 1994 square inches respectively, as shown by the outer lines surrounding the shaded portion in Fig. 6, Plate 34. The neutral axis in this case is shown by the lower dotted line P P: it is obtained in the same manner as before in the iron ship, by multiplying the several portions of the section, Fig. 6, into their respective leverages or vertical distances from the line P P, so as to make the moments equal above and below that line; the only difference for the wood ship is that here the ultimate resistance of the timber to compression is taken as 3-4ths of its resistance to tension. This gives the neutral axis P at 6¾ feet above the centre line of the bottom flange of the girder in Fig. 6, dividing the lower sides into two portions of 1041 and 695 square inches respectively above and below the neutral axis.

The weight of the 1200 ton wood vessel without cargo is 18 cwts. per ton measure, or 1080 tons total, as previously stated. Deducting 143 tons for the weight of the rigging, outfit, water, and stores, the same as in the iron vessel, the weight of the hull is 937 tons; half of which, or 468 tons, is therefore taken as the equivalent load at the centre. The internal capacity of the wood ship having been already stated to be only 933 tons as compared with 1108 tons capacity of the iron ship, the total distributed load of 1945 tons carried by the iron ship will be reduced in the same proportion, amounting to 1638 tons: and the equivalent centre load being 74 per cent. of the distributed load, as before, amounts in this case to 1212 tons. The total centre load is therefore 1680 tons, or 840 tons at each end of the ship, with a leverage of half the unsupported length of the vessel or 92½ feet.

Hence the strain tending to produce fracture at the centre of the vessel will be 840 tons $\times$ $92\frac{1}{2}$ $\div$ $6\frac{3}{4}$ = 11511 tons tension upon the portions of the section below the neutral axis, Fig. 6, Plate 34. The effective area resisting this strain is 5216 square inches for the bottom portion, and 1-4th of 695 or 174 square inches for the sides below the neutral axis; since the centre of gravity of the sides, from the neutral axis P down to the point R in Fig. 5, is only 1-4th of the way down from the neutral axis P to the centre line of the bottom portion, as seen in Fig. 5. The total effective area resisting tension is therefore 5390 square inches, on which the above load of 11511 tons produces a strain of $2\frac{1}{8}$ tons per square inch.

In the opposite case of the vessel supported only at the centre, the top is in tension, and the decks are therefore not included in the resistance. The neutral axis, found as before, is shown by the upper dotted line Q Q, Plate 34, which is situated 14 feet below the centre line of the upper portion, Fig. 6, or 6 inches above the previous neutral axis P; thus dividing afresh the 1736 square inches area of the lower sides into two portions of 935 and 801 square inches respectively above and below the neutral axis Q, as seen in Fig. 6. The weight of the hull, 937 tons as before, is equivalent to half that amount or 468 tons at the two ends; while the distributed load of 1638 tons in the wood ship is equivalent to 44 per cent. of that amount or 721 tons at the two ends. Hence the total load at the two ends is 1189 tons, one half of which or 594 tons is acting at each end by tension on the upper part of the vessel, at the leverage of $92\frac{1}{2}$ feet as before.

The strain tending to produce fracture at the centre of the vessel is therefore 594 tons $\times$ $92\frac{1}{2}$ $\div$ 14 = 3925 tons tension upon the portions of the section above the neutral axis Q, Fig. 6. The effective area to resist this strain, found as before, is 1011 square inches for the main deck portion, together with $\frac{3}{4}$ of 764 or 573 square inches for the top sides between the decks, $\frac{3}{8}$ of 1074 or 403 square inches for the lower deck portion, and $\frac{1}{7}$ of 935 or 134 square inches for the sides below the lower deck. This gives a total effective area of 2121 square inches resisting by tension, upon which the above load of 3925 tons produces a strain of $1\frac{7}{8}$ tons per square inch.

Thus if the average tensile strength of all the wood employed in the longitudinal timbers and decks of the ship, namely teak, greenheart, elm, and pine, be taken at 6 tons per square inch in the solid material, and the effective strength be taken at one third of that amount or 2 tons per square inch, in order to allow for the joints, the result obtained is that the greatest possible strain to which it could be exposed, namely in the case of the vessel being supported at the ends only, is $2\frac{1}{8}$ tons per square inch, as above ascertained, or 6 per cent. in excess of the tensile strength of the material: while in the other case of the vessel being supported only at the centre, the strain of $1\frac{7}{8}$ ton per square inch is 6 per cent. less than the strength of the material. In the iron ship, if the tensile strength of the material be taken at 20 tons per square inch, and the effective strength at three fourths of that amount or 15 tons per square inch, the greatest strain to which it can be exposed, namely 17 tons per square inch in the case of the vessel being supported at the ends, exceeds the strength of the material by 13 per cent.; and in the opposite case of the vessel supported at the centre, the strain of 13 tons per square inch is 13 per cent. less than the strength of the material.

The general result therefore as regards the comparative strength of the iron and wood ships appears to be that in the position causing the greatest possible strain in each case, namely when the ship is supported at the ends only, the strength of the material is deficient for resisting the strain by about one eighth in the iron ship and one sixteenth in the wood ship: and in the other position of strain, namely when the ship is supported in the middle, there is an excess of strength in the material of about one eighth in the iron ship and one sixteenth in the wood ship. A very important consideration however affecting this comparison of the strength of iron and wood vessels is that the wood vessel selected for the comparison is one of the very first class, as constructed by the first builders in this country; whereas nearly all foreign vessels and most others in this country besides the special few referred to are very much inferior to the one on which the calculations have been founded.

The iron used in the framework of iron vessels is applied in various forms of section of single or compound structure. Those which are principally employed are shown in the sections, Figs. 7 to 30, Plates 35 to 38, all drawn to a scale of one tenth full size.

For Keels, the section shown in Fig. 7, Plate 35, is that in most common use, as seen at L in Fig. 3, Plate 33. It consists of a plain parallel bar S, Fig. 7, about 8½ inches deep by 3 inches thick for a 1200 ton ship. This is forged in lengths of about 20 feet, and then pieced up by welds into two or three lengths for the entire ship, having scarfed joints of a length of eight times the thickness of the keel, which gives room for as many rivets as are required to correspond with the section of the keel. Fig. 9 is a deep keel of plate iron, made by putting two or more plates side by side, breaking joints in every way. The plates are 1 or 1⅛ inch thick and from 3 to 4 feet deep: they are adopted when a forging of the required size would be too large and heavy, say for vessels of 2000 tons and upwards; and where the scarfing would also be comparatively imperfect. This arrangement is specially adopted in order to be made to serve as a keelson as well. The floor angle irons T T have to be turned up at the foot so as to be rivetted through and through the keel plates; and the floor plates U U are thus made in two pieces, one on each side of the keel. The keelson angle irons V V are put on the top of the floor plates and rivetted through and through the top edge of the keel plates. Fig. 10 is the "dished" keel, specially suited to flat bottomed vessels, in which it forms an excellent trough for drawing off the last drop of bilge water. It is made of plates about 1 inch thick bent or rolled to the required section. The trough is made of a shape to suit the circumstances, from 6 to 8 inches wide and 2 to 4 inches deep. Fig. 8 shows an arrangement with a flat plate as a substitute for a keel for flat bottomed vessels, where the draft is limited to the smallest possible amount; and a watercourse is obtained by an opening W in the bottom edge of the floor plate U and by cranking up the angle iron to correspond.

For Keelsons, the section shown in Fig. 11, Plate 36, is that required by Lloyds' rules, and is 2-3rds the depth of the floor plates. Fig. 12 shows the box keelson, seen at G in Fig. 3, Plate 33, which

is recommended as superior to the preceding, its advantages being the larger section of the top member and the lateral stiffness obtained by the box form. Fig. 13 shows what is called the "intercostal" keelson, seen at H H in Fig. 3, which is of great value in keeping the floor plates in a vertical position so as to retain their best strength. It consists of short pieces of plate X, introduced between the floor plates U and rivetted with angle irons Y to each of them; thus forming a continuous line fore and aft, with double angle irons Z back to back rivetted through the top edge of all the intercostal plates. Fig. 14 shows a box keelson which is intercostal also: this is made either with double intercostal lines of plates X X, as shown in the section; or with a single line only, by one side only of the keelson being let down between the floor plates, instead of both sides.

Plate 37 shows sections of different forms of Stringers. Fig. 15 is a gunwale stringer, such as is usually adopted, as seen at A in Fig. 3, Plate 33. The word "gunwale" is employed to designate the group of iron used along the edge of the main deck at the sheer strake C; and the horizontal flat plate A, Figs. 15, 16, and 17, Plate 37, is called the gunwale stringer, and the angle iron B the gunwale angle iron. The size of the gunwale stringer A is 36 inches wide by $\frac{5}{8}$ inch thick in the midships for a vessel of 1200 tons. The inner angle iron D is specially valuable as forming an abutment for the edges of the deck planks. Fig. 16 is a box form of gunwale, which has special stiffness and solidity. Fig. 17 shows a form of gunwale with a vertical stringer E, consisting of an inner plate set up on edge; the groove between this stringer and the sheer strake C is made to receive the wood stancheons F for the bulwarks, and between the stancheons the groove is filled up solid with wood. Figs. 18 and 19 are two forms of stringer specially suited for lower hold stringers, or for any position where they cannot have the advantage of being connected to the end of deck beams: Fig. 19 is seen in position at KK in Fig. 3, Plate 33. Fig. 20 is a box form of lower hold stringer, suited for similar positions to Figs. 18 and 19, but capable of being made of much greater strength and stiffness.

Figs. 21 to 26, Plate 38, are sections of different forms of Deck Beams; amongst which may be specially noticed Fig. 22, because

with this section the largest amount of strength is obtained with the least weight of material, since the iron is in the form best suited for bearing a superincumbent weight and there is no loss of material by laps of rivetted joints. By the aid of improved machinery this section, Fig. 22, is now rolled to a depth of 16 inches and a length of no less than 60 feet.

Figs. 27 to 30, Plate 38, show sections of different forms of Frame Iron. Of these Fig. 28 is that mostly used; and it possesses the advantage of the reversed angle iron being curved off at the bilges across the bottom of the vessel, to form the top of the floor plates. The three other sections, Figs. 27, 29, and 30, are decidedly better so far as the side frames are concerned, but are not so well adapted to combine in the formation of the top of the floorings.

The use of iron in the construction of vessels affords great facility for obtaining the necessary strength in keels, stem and stern posts, and screw port frames, &c., by the introduction of large forgings. An illustration of this is afforded by the stern post and screw port frame of the "Great Britain," shown in Figs. 31, 32, and 33, Plate 38, which was introduced in the extensive repairs executed by the writer's firm in Liverpool after the stranding of the ship in Dundrum Bay. The total weight of this framework is about 25 tons: it was put in about the year 1853, and has continued sound and efficient during the constant working of the vessel up to the present time. The "Great Britain" is a good example of the strength and power of resisting damage possessed by iron vessels; for although on the occasion referred to she was stranded for a period of nearly twelve months, and was during that time subject to the severe strains caused by the buffeting of the waves and heavy weather, yet she was ultimately drawn off in safety and was found capable of perfect and efficient repair. The sheer of the vessel along the gunwale was preserved unimpaired throughout, showing the thorough stiffness of the structure as a whole; and although the damage was very serious in amount, yet it was entirely local, being mainly confined to large holes and indentations in the bottom of the ship. A wood ship under similar circumstances it is hardly necessary to observe would have had but a small chance of surviving at all.

The application of iron for building vessels is peculiarly advantageous in the special class of Screw Colliers that have recently come into use, with hollow bottoms for carrying water ballast. The traffic in which these vessels are engaged does not usually provide any return freight, and it is obvious a great commercial advantage is obtained by this method of water ballasting for the return voyage, which is accomplished without any delay and with but little cost. Figs. 35 and 36, Plate 39, show transverse and longitudinal sections of an iron screw collier with water ballast, in which it will be seen that a water chamber is formed by the hollow space of the double bottom G G, and a chamber is also obtained in each of the extreme fore and aft compartments H and K, Fig. 36. When the vessel is required to be ballasted, the large sea cocks are opened and water is admitted into the hollow bottom G and the aft compartment K, so as to fill these two portions; and then the water is also admitted into the fore compartment H, to such an extent as may be found necessary for adjusting the draft of water and the due immersion of the screw. When the vessel has arrived in port, the steam pumps are set in action for pumping out the ballast water; or in a dry harbour at low water the large sea cocks are opened, and then the water is easily and quickly got rid of within the short time of the cargo being taken on board: and the vessel is thus got ready for sea again without having experienced any delay on account of discharging ballast. Figs. 35 and 36, Plate 39, represent the iron screw steamer "Annie Vernon," which is of 518 tons gross register, and 70 horse power. The weight of water ballast contained in the hollow bottom chamber G is 120 tons, in the aft compartment K 20 tons, and in the fore compartment H 30 tons, making a total of 170 tons of water ballast; and the cargo of coal or iron ore which the vessel carries is about 700 tons. The mean draft when in ballast is 8 feet, and when fully loaded with cargo 13 feet, as shown in the transverse section, Fig. 35.

There is perhaps no branch of iron shipbuilding in which more special advantages are obtained from the use of iron than in the construction of Flat Bottomed Boats for river navigation. The extremely small draft of water thereby obtained may be said to be utterly impossible except by the use of iron as the material of

construction. An illustration of what is not an unusual specimen of vessels of this class is shown in Figs. 37, 38, and 39, Plate 40, which represent an iron paddle steamer, 226 feet long, 30 feet beam, and 7 feet depth of hold, fitted with engines of 170 horse power. This steamer draws only about 2 feet of water when light, and can be loaded with coal and cargo to a depth of 4 feet; it maintains a speed of 14 statute miles an hour when steaming alone, and 11 miles an hour with one barge in tow, 200 feet long and 30 feet wide with 370 tons of cargo on board, having a draft of 4 feet. In this construction of vessel two longitudinal iron girders II are introduced, rising considerably above the level of the deck, in addition to the sides of the vessel being raised as girders to the height of the paddleboxes, as shown at JJ, Fig. 37. The girders II are required in order to obtain the necessary longitudinal strength as a girder for carrying the weight of the engines and coal, the hull of the vessel being totally insufficient for this on account of its necessary shallowness and lightness. This vessel is made without a keel, as seen in Fig. 37; and with a spoon bow, as shown in Fig. 38, which is found to be a very advantageous form for facilitating getting the vessel off the sand banks that are so frequently met with in such rivers as the Ganges and Indus where these vessels are worked, in which it is found impossible to avoid at times going aground on the sand banks.

A novel system has recently been tried on the Indus for conducting the navigation by means of Bourne's floating steam trains, one of which is shown in Fig. 40, Plate 41. It consists of a paddle steamer L at the head of the train, having a convex stern fitting into the concave bow of the barge M next adjoining; and this barge has a concave stern which receives the convex bow of the second barge N. Other following barges OO, all with convex bows, are fitted together in a similar manner to the second barge, making up a train of five barges with an entire length of 640 feet including the steamer. The connexions between the barges are formed by a pair of radial connecting rods with ball-and-socket joints, thus making an articulated train capable of bending into any tortuous line that the navigation of the river may require. This system has not at present answered so well as was expected: the current of the river, both when

with the train and when against it, is found to prevent that due control in steering the train which is requisite for keeping it in the winding course desired. The special advantage supposed to be obtained is that of having only one midship section for all the train, instead of one midship section for the steamer and one for each of the five barges: but it will be observed that this advantage, even if assumed to be ever possessed, cannot be realised whenever the train is out of the straight line, since the resisting area will then be necessarily increased in proportion to the curvature of the train.

Fig. 41, Plate 42, shows the area of canvas requisite to drive a first-class merchant ship of 1200 tons burthen, the size of vessel shown in the previous drawings, Figs. 1 to 5, Plates 32 to 34. This is the proportion usually adopted in first class vessels, giving a total area of 23,313 square feet of canvas. The area of the immersed midship section when laden being 612 square feet, the proportion thus obtained is 38 square feet of canvas per square foot of midship section immersed. This proportion is found in general practice with good models of ships to obtain with a good breeze of wind a speed of 12 knots an hour.

A question of great importance and interest that has recently arisen in reference to iron ships is, what is the advantage to be obtained by the use of steel in place of iron in their construction. The best steel used for this purpose is guaranteed to bear a tensile strain of 40 tons per square inch, while the best iron will bear only about 20 tons per square inch or half the strain. This would show that half the weight of steel might be adopted as an equivalent for the iron; but in practice it is not considered advisable to reduce the proportion lower than two thirds the weight of iron. Taking the matter in a mechanical point of view, there can be no objection to the adoption of steel for the purpose so long as it comes up to the professed standard of quality: but considering it commercially, the comparison is as follows, if the price of iron be taken at the average rate of £10 per ton, and the steel at £26 per ton. The iron in the hull of a 1200 ton ship as before stated is 612 tons, which taken at £10 per ton costs £6120. Then two thirds that weight of steel or 408 tons

at £26 per ton costs £10,608. This shows the weight of the vessel to be reduced 204 tons by the use of steel, and its carrying capability thereby increased to the same extent; but this is obtained at an increased cost of £4488 as respects the raw material, or at the rate of £22 per ton for the additional weight carried. On the other hand the whole cost of the iron ship of 1200 tons, taken at £20 per ton, is £24,000; and its actual carrying capability being 1800 tons, its cost is about £13 per ton for the weight carried. It thus appears that the additional 204 tons of cargo would be carried by steel at a cost of £9 per ton more than by the iron bottom; and with this serious additional drawback, that with the steel the increased capability for carrying weight is not accompanied by any corresponding increase in internal capacity, as would have been the case if the additional weight had been carried by proportionately increasing the size of the iron ship at the lower rate of cost.

The above comparison would of course be reduced by risking a smaller proportion of steel, as well as by any reduction in its price. But in order to bring the two ships to an equality as regards total cost, it would be requisite to reduce the weight of steel as low as half the weight of iron and to reduce the price to £20 per ton, when 306 tons of steel would cost £6120 or the same amount as the iron. In that case the vessel would be able to carry additional cargo equal to the increased difference of weight, namely 306 tons, without additional cost; although without any corresponding increase of capacity for containing this additional cargo.

The mode of rivetting adopted in large first-class vessels is principally what is termed "chain rivetting," both in the longitudinal and vertical joints: but in addition the principal stringer plates in the upper part of the vessel, and the sheer strakes in the midships, have further rows of rivets with increased lap of the joint plates, making the joints in these cases treble or quadruple rivetted. The relative merits of holes punched or drilled appear to be not so different and not so much in favour of the latter as might be expected: the punched holes are not so regular and so direct through the thickness of the plates as the drilled holes; but notwithstanding this it is found

in practice that the punched holes are thoroughly well filled by the rivets, which adapt themselves exactly to all irregularities of the holes; the drilled holes though perfectly parallel throughout are not better filled by the rivets than the punched holes, as is seen in the two specimens now exhibited, showing sections of plates rivetted together, one with drilled holes and the other with punched holes. It must be admitted at the same time that the plates are subjected to a somewhat greater strain by being punched than by being drilled, though the damaging effect from such a cause cannot be said to be at all apparent in the usual execution of good work.

The joints for the plating have now become more perfect than formerly, by the use of the planing machine. The edges of the plates for the butt joints are now planed perfectly straight and smooth, and they are thus brought into accurate contact with each other, so as to form a perfectly true and close joint, which could not previously be attained by shearing and the too common practice of hammering up the edges of the plates. All necessity for undue caulking and the use of lining strips is now avoided, and the best strength of the material is imparted to the ship. The quality of iron employed for ship building should in all cases be equal to a tensile strength of at least 20 tons per square inch; and a direct and habitual system of testing should be constantly carried out.

An important point connected with the construction of iron ships is the kind of tools employed and their special adaptation to the purposes for which they are required. Great improvements are constantly being introduced to meet the varied requirements as they arise from time to time, in order to accomplish greater accuracy and perfection of work with increased economy and dispatch. The ordinary tools in general use, such as punching and shearing, drilling, and bending machines, need not be specially referred to here: but attention may be called to some improved machines that have been recently adopted with very considerable advantage. Amongst these may be named a punching and shearing machine, which is fitted with sliding tables and is self-acting, by the use of which three or more holes can be punched at one time, and each of the four edges of the plates perforated as required with perfect accuracy and truly square with one another; and

the shearing also of the four edges of the plates can be made perfectly straight and true, and nearly as smooth as if planed, the smallest width, even down to 1-64th inch, being accurately pared off the edges of the plates. Another machine is a plate-planing machine, by which the edges of the plates may be planed perfectly true with only one or two cuts; thus enabling the workmen to make the most perfect joints with great economy of time and labour. Another machine is a horizontal punching machine, whereby long curved frames may be punched while held in a horizontal position, thus dispensing with the necessary tackle and high roofs necessary if they were to be punched by an ordinary machine, which would require them to be held in a vertical position. The small machine for straightening angle iron by means of pressure from a screw, which is done silently and with perfect effect, is a great improvement upon the old plan of always doing this by the blows of heavy sledge hammers. Another machine specially useful and productive of economy is the multiple drilling machine, whereby a number of holes, up to twelve or even more, can be drilled at one time in keels, stem and stern posts, &c., with more accuracy of spacing than could possibly be obtained with the ordinary machines which can drill only one hole at a time.

The very extensive use of iron vessels at the present time has now proved that the only objections which can be urged against them are the liability of the bottoms to become foul by the adhesion of animal and vegetable substances, and the derangement of the compasses by the local attraction of the iron in the hull. First as regards the fouling, it has to be observed that the difficulty only exists in the case of vessels engaged on very long voyages, or detained at foreign ports where the water and climate are such as to encourage the growth and accumulation of those substances. This difficulty it must be admitted does exist to some extent with iron ships, and occasionally results in a considerable detention and delay: usually however vessels that are well coated with any of the suitable compositions now so extensively in use, which are destructive to animal and vegetable life, are able to prosecute their voyages out and home in almost any part of the world, without ever becoming foul at all, or at least to any extent that is seriously detrimental. The discovery of still better compositions will

probably lead almost to the annihilation of this difficulty; and even if they do not effect this, there is no doubt that the graving docks, both on land and floating, and the slips that are now being adopted on such a large scale at many important foreign ports will give as great facilities for docking and cleaning the vessels as are possessed in this country, and thus remove the difficulty entirely. Secondly as regards the derangement of the compasses in iron ships by the local attraction of the metal in the hull, this exists in all ships to a greater or less extent, and perhaps there are no two vessels that are exactly alike in this respect. The mode adopted for meeting this difficulty is to neutralise the attraction by fixing permanent magnets in suitable positions found by a series of trials in each particular ship, the effect of which is to make the compasses nearly correct: the precise amount of incorrectness that still remains is then depicted upon what is called a card of errors for every position of the compasses. This plan affords practically the same results for working the ship as if the action of the compasses themselves were perfectly correct.

An application of iron or steel in place of hemp is now in use in first-class vessels for the standing or fixed rigging, that is those portions that are not what is termed running rigging. The effect of this change in a 1200 ton ship is that by adopting iron wire rope in place of hemp a saving in weight is effected of 3 tons, and in cost a saving of £200; and with steel wire rope the saving in weight is 6½ tons over hemp, but without any further saving in cost over the iron wire rope. Greater durability is obtained by the use of wire rope, and damage by moisture is prevented by the wires being galvanised, as well as by covering the wire rope in some cases with a serving of hemp yarn.

The adoption of steel and iron in place of wood for the masts and yards, which is now becoming so extensive, is a subject that requires to be well considered in order to secure the real advantages to be attained by the change of material, and at the same time to avoid the risks and dangers that would arise from making the change in an injudicious manner. That a saving of weight is effected by this change is shown by the fact that in a 1200 ton vessel the three lower

masts and the bowsprit if made of iron weigh 26 tons, and if made of steel 19 tons, while if made of wood they weigh 32 tons. A corresponding advantage as regards weight is obtained by the use of iron and steel for the topmasts and yards: the weight of the three lower yards if made of iron is 8 tons, and if made of steel 5 tons, while if made of wood their weight is 9 tons. It may therefore be taken as approximately correct that if iron were wholly adopted for the lower masts, topmasts, bowsprit, and principal yards of a 1200 ton ship, an entire saving of 7 tons would be effected, which saving would be increased to 17 tons if steel were used.

An important point to be noticed in reference to this saving of weight is that it is effected at a position situated at a great height above the centre of gravity of the vessel. Thus in the case of a vessel being light, as for instance during the interval of time between discharging one cargo and taking in another, the saving of 17 tons weight resulting from the use of steel for the masts and yards will take place at a point P, Fig. 34, Plate 38, which is 32 feet above the centre of gravity Q of the vessel in that condition. Hence the centre of the temporary ballast R being 11 feet below the centre of gravity Q, it may be concluded that the result obtained by the saving aloft will be that more than 30 tons of ballast may be dispensed with in the bottom of the hold.

An experiment of some practical interest to show the comparative strength of one of the best pitch pine yards and a cast steel yard of the same dimensions has been carried out at the writer's works, of which the following are the particulars. The yards selected were the actual topsail yards that had been made for a 1200 ton ship, of the same external dimensions, namely 58 feet long, 15 inches diameter at the centre, and 7½ inches diameter at the ends, as shown in Figs. 42 to 45, Plate 43. For the testing they were carefully bedded upon timber supports 18 inches long with 51 feet clear length between, and were loaded in the centre by actual weights of pig iron in a cradle suspended by chains from a wood saddle S, Figs. 42 and 44, 2 feet long, carefully fitted upon the top surface of the yard. In each case the first load included the weight of the cradle and chains.

The successive loads and corresponding deflections of the two yards were as follows :—

1863.	WOOD YARD.		STEEL YARD.	
	Load.	Deflection.	Load.	Deflection.
	Tons.	Inches.	Tons.	Inches.
23 July	1·29	3·50	1·85	2·25
	1·55	4·00	2·06	2·50
	1·81	4·50	2·35	2·87
	2·08	5·25	2·63	3·19
	2·37	6·00	2·89	3·50
	2·55	6·50	3·10	4·12
	2·83	7·25	3·25	4·50
	3·09	7·75	3·46	4·75
	3·35	8·50	3·60	broken
	3·63	8·87		
	3·91	9·37		
	4·16	9·87		
	4·41	10·25		
	4·65	11·37		
	4·86	11·75		
	5·11	13·00		
	5·38	13·62		
	5·77	16·00		
	6·06	16·50		
	6·41	17·00		
	6·57	17·25		
24 July	6·61	21·50		
	6·85	22·25		
	7·09	23·00		
	7·31	23·75		
	7·52	24·50		
	7·83	25·50		
25 July	7·98	41·00		
	8·04	broken		

The wood yard, of pitch pine, had the load removed on the nights of the 23rd and 24th July, to allow of packing up the ends higher from the ground; and was left unloaded during the whole of those nights. At the end of the second day's testing, at the deflection of 25½ inches under 7·83 tons load, the wood began to show signs of fracture on the upper side: but the yard did not finally give way until the load of 8·04 tons was reached. The extreme deflection just before breaking was 41 inches, as shown in Fig. 42, Plate 43, being nearly 1-16th of the length of the yard. The fracture was very perfect in character, the lower side showing the effects of the

tensile strain by longitudinal rents extending for so great a length as 12 feet; and the upper side showing the effects of the compression by the material being crushed up into a lump projecting above the line of the upper side of the yard at each end of the saddle piece; whilst the centre portion for nearly half the diameter, occupying the position of the neutral axis, broke off short and square, as seen in Fig. 43.

The steel yard, tested on the 22nd July, broke first at the point T, Fig. 44, Plate 43, about 6 feet from one end or 2½ feet from the support; and then on falling it broke at the point U, 5 feet from the centre on the opposite side. The first fracture T went completely round, and showed on examination a flaw or rather an old crack for almost a fifth of the circumference. The second fracture U did not go quite round, but opened about ⅛ inch on the bottom side. The section of the yard, Fig. 45, was very little altered by the load, and the top showed very little sign of buckling.

The general result of this experiment is that the steel yard broke with a little more than 3½ tons load, and with 4¾ inches deflection; whilst the wood yard required 8 tons to break it, with a deflection of 41 inches. It is only fair to observe however that in the manufacture of this steel yard some of the plates intended to be used were considered of inferior quality, having proved brittle whilst the yard was being made: but these were replaced by good plates at the time, so far as they could be discovered.

The Chairman remarked that the construction of iron ships was a subject of such vital importance in a large seaport like Liverpool that he was sure the excellent paper just read would be highly appreciated by the meeting, and they would feel greatly indebted to the author for having prepared it.

Mr. P. D. Bennett asked for some further explanation about the mode adopted for calculating the strength of an iron vessel as a girder. He could understand that when it was supported at the

two ends the large amount of metal in the keel and bottom of the hull formed the bottom flange of the girder, resisting the strain of tension to which the bottom of the vessel was then subjected; but there appeared to be so little metal at the decks of the ship to act as a top flange for resisting the corresponding compression that he did not see how a vessel could be treated as a girder in that way. And in the contrary case of the vessel being supported in the centre, it then became a double cantilever, with scarcely any top flange for resisting the tension, and an excessive bottom flange for compression. Moreover in calculating the strength of wrought iron box-girders it was usual not to include the sides in the calculation, but only the top and bottom members of the girder; and he enquired how the sides of the vessel were taken into the account in calculating the strength of a ship when it was treated as a girder, as in the present paper.

Mr. Vernon replied that he had not attempted to apply to the case of a ship any arbitrary formula such as was used for ordinary box girders; because, although such a formula could be safely employed for rectangular box girders, from their general correspondence in distribution of material, yet in a ship the special form in which the material had to be distributed to meet the carrying and floating requirements necessitated so wide a departure from what would be the most effective distribution of the material in a box girder, that to treat the vessel as a box girder could not afford any satisfactory results. In the ship accordingly the plan he had taken had been to collect together the sections of metal in the entire midship section of the vessel, grouping the whole into a few separate portions at the points where the greater mass of the material was situated; and the result was a section of solid girder of the form shown in the diagram, Fig. 4, Plate 33, having two upper flanges corresponding in position to the upper and lower decks, and one bottom flange corresponding to the keel and bottom of the vessel, the chief portion of the material being by the construction of the vessel mainly concentrated at those three parts. The sides of the ship however necessarily contained also a large portion of material, and when brought together in the same way they formed the middle vertical web in the girder; and then the ultimate breaking strength of the

whole was calculated approximately by taking the area of each of the three flanges and also of the middle web, and taking the distance of the centres of gravity from the neutral axis, as the leverage at which the several areas acted to resist the strain; allowing for the difference in ultimate strength of the material under tension and under compression. By this means two positions of the neutral axis were arrived at, one when the ship was supported at the ends, and the other when it was supported in the middle; in the latter case the two upper flanges of the diagram girder, corresponding to the material in the upper and lower decks of the ship, were in tension, acting then like the bottom flange of an ordinary box girder. By this mode of procedure he had attempted to arrive at an approximate estimate of the ship's strength, endeavouring to give neither too much nor too little value to any portion of the material, but to take as nearly as was practicable the effective value of each portion corresponding to its actual position in the construction of the vessel: and the object being to institute a comparison between the strengths of iron and wood vessels of similar form and size, the calculation though not assumed to be absolutely correct would afford a relative result of very considerable correctness.

Mr. T. R. Arnott observed that the addition of a pair of longitudinal box girders or strong deck beams had been recommended by Mr. Fairbairn, for strengthening the upper portion of the section of iron ships to resist the strains of tension and compression; as there appeared a deficiency of material at that part in the present construction of iron ships, when considered as a girder subjected to vertical strain.

Mr. Vernon said the deficiency of material in iron ships was certainly in the upper deck, as pointed out, and that was therefore the place where any additional material ought to be put; and no doubt the addition of longitudinal box girders as had been suggested was highly desirable and would greatly increase the strength of the vessel. The paper that had been read had been confined to the actual practice at the present time in building iron and wood ships, for the purpose of enquiring into the safety and correctness of the present mode of construction; and the same principles of investigation would

be applicable to any new distribution of material which might be adopted for obtaining greater strength in the ship.

Mr. H. W. HARMAN observed that the question of the relative value of punched holes and drilled holes in rivetted work, which had been referred to in the paper, was really a very important one at the present time when iron entered so largely into all sorts of structures. Although drilled holes were thought to be necessarily the best, yet he considered the old fashioned punched holes had some advantages, the principal of which was that the punching afforded a rough test to the workmen as to the quality of the iron punched, leaving minute cracks in the burrs punched out in the case of bad or inferior iron, which were of great value in disclosing the quality of the metal: whereas drilling afforded no such test, passing equally through bad or good material, without furnishing any such indication of the quality. He therefore thought punching furnished a valuable criterion, and was not likely to be superseded by drilling, except in particular classes of work where extreme accuracy of the holes might be necessary. Punching had also the advantage that the punch inevitably made the holes slightly taper, giving the effect of a countersink; so that if two plates were rivetted together with the smaller ends of the holes inwards, a rivet would remain secure in its place and hold the plates together even without its head: but in drilled holes if a rivet lost its head there was nothing to bind the plates together. Thus for all commercial purposes, and where anything like good quality of iron was used, punching would still appear to be preferable to drilling.

Mr. VERNON concurred in the value of punching as a test of the quality of the iron, and did not think the substitution of drilled holes would be attended with any great advantage in iron shipbuilding. He showed two sections of plates rivetted together, one with punched holes and the other with drilled holes, from which it was seen that the rivets filled the punched holes quite as well as the drilled holes; and he therefore concluded the rivetting would not be benefitted by drilling the holes instead of punching them. Certainly punching was a quick and ready means of ascertaining the quality of the iron by examining the holes made and the burrs punched out: if the iron were brittle or inferior, the burrs would be much starred, showing the

grain of the iron disrupted by punching; but if the iron were of a good tough quality, the burrs kept sound and showed no disruption of the metal. There was certainly some convenience in the slight countersink of punched holes, for giving greater security to two plates rivetted together with the small ends of the holes inwards: but this would not be the case with three such plates rivetted together, where there would be an undesirable enlargement of the rivet hole at some one part, causing a tendency rather to push the plates apart in the act of rivetting than to draw them together; and in practice therefore where three or more plates were rivetted together with punched holes it was necessary to pass a rimer through the holes, to get rid of the slight taper and make them more nearly parallel.

Mr. W. Richardson thought it would be rather retrograding in mechanical principle if drilling instead of punching were not persevered in for rivetted work, and even extended in application. The simple question was whether rivetted plates were any stronger with punched holes than with drilled holes, and his own opinion was that the reverse was the case; and certainly if the iron of the plates were of inferior quality in any instance, it would be better then to drill the holes rather than to punch them, in order to avoid as far as possible putting any strain on the metal. As to the advantage of the conical holes obtained by punching, the countersink could readily be made in drilling by using a countersink or slightly conical drill; but with punched holes crooked rivets must inevitably occur, since it was impossible to get the punching done with such accuracy as to ensure all the holes being truly in line with one another in the two plates rivetted together.

Mr. J. J. Birckel had known some experiments made on punched plates by a member of the Institution, Mr. W. Anderson of Dublin, in which it had been found that the iron was considerably deteriorated in strength by punching the holes, as compared with drilling them.

Mr. Vernon said that although the act of punching must of course be to a certain extent injurious, by throwing some strain upon the iron surrounding the hole, yet it was found in practice that, by properly proportioning the welt or overlap of the plates, excellent

joints were made in rivetted work with punched holes, and the work so rivetted was not deficient in strength at the joints compared with other parts. As to the relative value of punched holes and drilled holes, he was not able to express a preference for either as absolutely superior to the other, and could merely state that from present experience the drilled holes for rivetting did not appear to have any advantage over punched holes for the purposes of iron shipbuilding.

Mr. J. McF. Gray remarked that the experiment which had been described as to the relative strength of wood and steel spars showed that, when the spars were exposed only to the strains produced by dead weights, their strengths were as two to one. But the disparity of strength would have been found much greater if the spars had been tested by blows by a weight falling from a height, instead of by a dead weight simply resting on the spar. In practice more breakages were caused by a sudden blow or jerk, as in the case of a chain riding and slipping a link, than by any steady pressure or strain upon the spar. He enquired how much heavier the steel spar would have to be made, in order to be as strong as the wood spar in withstanding a blow.

Mr. Vernon replied that he had not attempted testing the spars by the blow of a falling weight, but had loaded them with gradually increasing weights, as described in the paper, until they broke under the load. He had not ascertained the weight of steel that would be required to make a spar as strong as the wood spar had proved: but in addition to its greater strength the superior elasticity of the wood spar was certainly remarkable, the deflection amounting to as much as 41 inches or nearly 1-16th of its length immediately before breaking under the load of 8 tons, whereas the steel spar deflected only 4¾ inches or less than 1-8th of the amount before breaking under 3⅝ tons load.

The Chairman observed that among the sections of iron now employed in the construction of iron ships there were some of very large size, as shown in the drawings exhibited, and he enquired where the rolling of such large sections was carried on, some of them being as deep as 16 inches and 60 feet long all in one length.

Mr. E. Reynolds said he had seen solid rolled beams 12 inches deep with flanges 5 inches wide at top and bottom, and believed some rather larger sections had been attempted in France; but that appeared to be the extent to which the rolling could be carried at present, as such a depth of section made it necessary to start with a pile of extravagant dimensions, and to have a large number of grooves in the rolls to reduce the thickness of the metal very gradually; because in the process of rolling those large sections each passage of the iron through the rolls would reduce the middle web perhaps 20 per cent. in thickness, while the top and bottom flanges would be reduced only 5 per cent., causing an undue stretch on the flanges which tore them unless the iron were very good; so that great practical difficulty was experienced in rolling the girder sound. He had seen the large beams made at Butterley for the "Warrior," 16 inches deep and 60 feet long; but those could hardly be called solid rolled girders, being almost as much built up as if they had been rivetted; they were built up of two T irons, each made of two or three lengths welded together, forming respectively the upper and lower half of the girder, and these were then welded together along the centre of the web throughout the entire length, a special bar of H section being inserted between the upper and lower T irons and clipping the edges of both, the heating being accomplished by moveable fires and the welding by hammers striking simultaneously on opposite sides, welding the different portions of the whole length successively. Great difficulty had been experienced in accomplishing this at first, but now the process was successfully managed: and the T irons were easily rolled of large dimensions, for by passing them edgeways and flatways successively through the rolls the work done upon the iron by the rolls was equalised throughout the entire section of metal. Girders manufactured by this plan had been shown at the Exhibition of last year, 4 feet deep with flanges 9 inches wide; and it was clear that was by no means the limit of size if beams were built up in that way by welding.

Mr. T. W. Plum said he had superintended the rolling of the large rolled beam shown in last year's Exhibition, 12 inches deep with top and bottom flanges 5 inches wide, which was rolled at the Blaenavon

Iron Works in one solid section; it was passed through only five grooves in the rolls after leaving the roughing rolls, and was upwards of 40 feet long and 1 ton weight; though not so perfect as it might have been with further experience, it was the first beam rolled of so large a section and so great length. A large quantity of beams of the same section but shorter lengths had since been rolled at Blaenavon, and there was no real difficulty in rolling beams of that section as long as 60 feet in a single length. It was merely a question of the extent of furnace accommodation that was available for reheating, since such a section of beam would require reheating three or four times during the operation of rolling. In the formation of the pile for these heavy sections it was quite necessary to have a shaped pile, built up into something of the shape of the ultimate section required; otherwise sixteen or seventeen grooves in the rolls would be needed for working it down gradually to the finished dimensions. The outlay necessary for producing such work was too great to make it commercially profitable, unless the demand were large. The welding process employed at Butterley, as had been described, would no doubt make good work; but he thought that, as the demand increased, beams rolled all solid would be produced of still larger sections and greater lengths than had yet been done.

Mr. Vernon said he had not found in practice that such extraordinary lengths of beams were required according to the present construction of iron ships. The introduction of the forms of iron deck beams shown in the sections, Plate 38, was due to his late father and Mr. Kennedy; they had proved very successful, and their adoption had now become universal in iron shipbuilding. The several sections of iron shown in the drawings were those actually used in ships at the present time; but probably no limit could be assigned, as far as the requirements of deck beams were concerned, to the sections and lengths that would hereafter be produced by rolling.

Mr. Maxwell Scott observed that in the section shown of the ordinary construction of iron ships there did not appear to be any box girders rivetted on either side of the hatchways on the upper deck, running the length of the vessel, which would add materially to the strength; and he enquired whether the strength of the iron ships was

found by calculation to be sufficient without these, and whether the section as shown was all that was required by Lloyds' rules.

Mr. Vernon replied that box girders rivetted on each side of the hatchways in the decks were certainly a great advantage to the strength of the upper portion of an iron ship, preventing the decks from being at all weakened by the holes left in them for the hatchways. But he had not shown any girders at those parts in the section of vessel exhibited in the diagram, as that was intended to represent only the actual strength of iron vessels as at present built in accordance with Lloyds' rules, which did not require any provision of box girders alongside the hatchways. Many iron ships of that size, 1200 tons burthen, carried their cargo over long voyages without suffering any injury from the absence of this provision; but in larger vessels he considered the box girders at those places would probably be needed for the safety of the ship, in addition to the usual box stringers added to the decks of large ships.

The Chairman remarked that it appeared from the calculations given in the paper that the main defect in iron ships as at present constructed was a deficiency of strength in the upper portion, and he believed several instances had occurred of iron vessels having their decks seriously strained in severe weather, and even their sides partly torn at the top, for want of the additional strength at that part which would be obtained by box girders along the deck.

With regard to the comparison between the wood and steel spars, the results obtained from the experiment were certainly very remarkable, as it would have been expected from all former experience that the steel spar would show a greater amount of elasticity. There was some doubt however, it appeared, whether the metal had not been strained previously in the manufacture of the steel spar; and he thought the place at which it broke indicated this, the breakage having been first at a point only 6 feet distant from the end of the spar. The saving of weight obtained by the substitution of steel masts and yards would be a great benefit to the sailing of the ship; but in the steel spar experimented upon there seemed a deficiency of material, and the reduction of weight had perhaps been carried rather too far

in that particular instance. A more important consideration however in practice than the ultimate breaking strength of the steel spar was its safe elastic limit; because practically the object to be aimed at was that the spar should be made so strong as never to be likely to receive any permanent set from any strain that it might be expected to meet with in the ship. The great advantage of steel in this respect had he understood been found by Mr. Mallet to be that its safe elastic limit was very high compared with that of iron: and in order to make the comparison complete, he would have wished, had it not been for the great expense of the experiments by the breakage of such costly spars, that a third spar of iron had been tried in the same way as the wood and steel spars, and all three of them in reference to the safe elastic limit of each.

Mr. Vernon remarked that, in reference to the deficiency of strength which had been shown to exist in iron ships from the want of longitudinal box girders in the decks, he had endeavoured rather to arrive at a clear and tolerably accurate comparison of the relative strength of iron and wood ships under the two extreme circumstances to which they might be exposed, than to establish the superiority of either or to advocate any particular mode of construction in preference to others for the iron ships. The general result he had arrived at, as stated in the paper, was that if a ship were supported in the worst position for its strength, namely at the two ends, the iron ship would be about one eighth deficient in strength and the wood ship one sixteenth deficient; whereas if supported in the middle, the iron ship would have an excess of strength of one eighth and the wood ship an excess of one sixteenth.

In the steel spar that had been experimented upon it seemed curious that the point where the breakage first occurred should be so near the end of the spar; but it must be mentioned that the longitudinal steel angles rivetted along the inside of the spar, as shown in the transverse section, Fig. 45, Plate 43, terminated about one foot short of the point of fracture, and therefore the spar was defective in construction, having a sudden change of strength at that place. The experiment on the two spars had certainly been a very costly one, and he would have hesitated to

undertake it but for the fact that no experiment on a reduced scale would have been satisfactory in disclosing whether the course now being pursued in the construction of steel spars was a safe one. The subject was felt to be one of so great practical importance that one gentleman engaged in the manufacture of steel had liberally offered to repeat the experiment on the steel spar at his own cost, in order to obtain a result free from any doubt as to the quality of the material employed and the perfect construction of the spar. Although the present experiment showed that the steel spar was inferior to the wood, it did not determine whether this was due to an inferior quality of material being used for the steel spar, or whether a spar made with the same weight of good steel would still be weaker than the wood spar. He therefore hoped to be able before long to give the results of further experiment on the subject, that a satisfactory conclusion might be arrived at, enabling iron shipbuilders to make steel spars of equal strength with the best wood spars.

The CHAIRMAN moved a vote of thanks to Mr. Vernon for his paper and the valuable information he had supplied, which was passed.

The following paper, communicated through Mr. John Pearson, was then read:—

ON THE EFFECTS OF SURFACE CONDENSERS ON STEAM BOILERS.

By Mr. JAMES JACK, of Liverpool.

Some three or four years ago condensation of the exhaust steam from marine engines by surface contact was looked upon as an experiment, and few steam ship owners could be induced to try this system, which was new to them: and notwithstanding the development and complete success of tubular surface condensers, both in merchant ships and in the navy, more than a quarter of a century ago, and the reduction thereby effected in the consumption of fuel, the objection was raised that surface condensation could not have the advantages alleged, or it would never have been discontinued. At the present time however it is no longer an experiment, but a reality: for not only have surface condensers been largely introduced with new engines, but in many cases injection condensers have been taken out of working vessels and surface condensers put in their place. As the writer's firm has constructed and fixed a considerable number of surface condensers during the last three or four years, and as certain actions have been found to take place on the tubes and plates of the boilers with these surface condensers, of such a character that the full advantages of the use of distilled water could not with impunity be obtained, it is the purpose of the present paper to give the particulars of these effects. The effects produced upon boilers where surface condensers are used must have been noticed by many engineers, and the object of the paper is therefore to induce discussion upon the subject and elicit information which will enable the great advantages in the saving of fuel resulting from the employment of surface condensers to be realised. As the boilers where surface condensers are used are insidiously and rapidly acted on, the danger

of delay and of accident from explosion is thereby greatly increased, rendering the question one of serious importance.

Surface condensation may be considered an old idea: for Savery adopted the principle in 1698 in what may be called the first steam engine, having applied cold water to the outside of the cylinder; and even Watt devoted much time to it, although he afterwards finally abandoned it, stating that the objection of the size and expense of the tubular condenser for large engines made him resolve to sacrifice part of the power to convenience, and to employ large pumps. It was about 1832 that surface condensation became practically carried out. Mr. Samuel Hall having seen its advantages constructed a surface condenser consisting of a casing containing a number of small tubes; and succeeded in overcoming the difficulty of making a tight joint between the water and steam spaces, which should allow for the expansion and contraction of the tubes. These condensers were introduced into both naval and mercantile ships; but although attended with considerable advantages they ultimately fell into disuse. Several modifications have since been proposed with different arrangements and constructions of the tubes, with the water inside instead of outside the tubes, or with a combined jet and surface condensation. There was a difficulty at first in obtaining some effective packing for the ends of the tubes: but after the long experience of india-rubber for the purpose it may now be pronounced a success; for out of many thousands of joints which the writer's firm have made, not a single case of leakage has occurred.

Surface condensation is a process by which both the sensible and the latent heat of the steam are conveyed away; and although the adoption of any new system is necessarily slow, the writer does not doubt but that surface condensation will ultimately entirely supersede the jet. There are evils however which require remedying before surface condensation can be universally adopted for steam ships; not in the condenser itself, but in the effects produced on the boilers by distilled water or something contained in it resulting from surface condensation. The writer will accordingly refer first to the effects of surface condensation on the boilers, and secondly to the probable cause of this destructive action.

A number of marine boilers which have come under the writer's observation, and may for convenience be distinguished by the letter **A**, had been in use for longer or shorter periods, none less than six months, supplying steam to engines having injection condensers. Salt water had been used for feeding the boilers, and a considerable incrustation had consequently taken place. Without going to the trouble and expense of cleaning these boilers, they were sent to sea immediately after the surface condensers were fitted in. Everything went on satisfactorily, and on returning from the first voyage the boilers were examined. It was found that the greater portion of the incrustation had fallen off, and that the surfaces of the boilers, that is the inner surfaces, were in very good condition for transmitting heat, showing that the adoption of distilled water for feed had been advantageous. Boilers of this class have uniformly had the incrustation nearly all removed by the action arising from the use of the surface condensers during the first voyage, and in every case the surfaces of the boilers have been found in good condition and still remain so, some of them now for as long a term as four years. Indeed surface condensation has here been in every sense a decided success.

The appearance of the inside of the boilers however was not that of clean iron. The surface seemed to be impregnated with some greyish matter, or to be altered in its chemical nature. That this impregnation or alteration of the surface prevented and still prevents injurious action on the metal will be gathered from a description of another lot of marine boilers, distinguished by the letter **B**, which were in all cases new boilers, sometimes with new engines and surface condensers, in other instances with old engines and new surface condensers. In port, before starting, a number of these boilers were filled with fresh water, while another number were filled with salt water. An examination after the first voyage, during which only distilled water had been used for feeding the boilers, showed the following effects, which were increased in every subsequent voyage, until the practice was adopted of feeding with say from one sixth to one tenth of salt water. First, both above and below the water line the surfaces of the plates, tubes, and rivets were covered with a

deposit resembling hydrated oxide of iron, which when the water was evaporated was in the state of a fine impalpable brownish coloured powder. This deposit was thickest above the water line, sometimes averaging $\frac{3}{4}$ inch thick. When the boilers were emptied a thick slimy deposit adhered all over the inside, an analysis of which showed that it consisted of

Oxide of Iron	77·50
Moisture	19·75
Grease	0·85
Sulphate of Lime	0·80
Oxide of Copper	0·60
Traces of Alumina and Chloride of Sodium and Magnesium	...
Loss	0·50
	100·00

Secondly, underneath this deposit the plates and tubes were found to be eaten into, indented, or "pitted." The indentations varied in diameter from the smallest speck to $\frac{5}{8}$ inch, and in depth from the merest impression to the entire thickness of the plates or tubes. And although they were formed all over the boilers, they were most frequently found and were most numerous just over the fireplaces, and in those parts immediately in connexion with the greatest heat. In some of these parts the surface was entirely covered with the indentations; while in other parts as much as a square foot of plate, although subjected to the greatest heat, was free from them. The plates and tubes in all cases have been of the best iron and by good makers, and the "pittings" occur in what looks like iron of good quality with a good fibre, no slag or cinder being perceptible. So destructive was this pitting in boilers using the same water over and over again, that in one instance the tubes of new boilers were actually eaten through at the end of two or three voyages, extending over only a few months altogether, and it became necessary to put in new tubes, and to use a portion of salt water for feed to keep up an incrustation, so that the boilers should not be acted upon. If the iron of the boilers had been all of one make, it would naturally have been concluded that the pitting was due to the quality of the iron; but as the iron of different boilers had been obtained from different makers from time to time, the quality of the iron could not be blamed.

The presence in the boiler of a soft metal, such as copper from the condenser tubes, it was considered would induce a galvanic action such as might affect the iron in some way. But the analysis which was made of the deposit scraped from the boiler shows that there was scarcely a trace of any foreign metal there. Indeed it might have been concluded that a soft metal could not be present, for the tubes of the condenser and the copper pipes were all in a perfect condition. Even at the joints, made tight by india-rubber hardened by vulcanising, there was scarcely a speck of corrosion.

A search was then made to ascertain whether the gluey deposit was present that arises from the decomposition of the tallow and oil used for lubrication; as the writer had frequently heard that such a deposit took place in boilers where Hall's surface condensers were used. For the purpose of ascertaining this the mud cocks of a vessel were not opened for some time before arriving in port; and the fires were then put out on arrival and the mud discharged, when the only substance found was the watery brownish deposit before referred to. The deposit remaining in the bottom of the boiler was carefully examined, but here again there was only the same deposit. As it was believed that the lubricating material carried into the boilers with the feed might by continued subjection to heat form an acid capable of producing the effects observed, the kind of lubricating material employed was noticed, in order to ascertain whether animal or vegetable oils acted most injuriously; but it was found that the action went on as much with the one oil as with the other. In case however a fat acid, formed as already mentioned, might be the cause, pieces of chalk were put into the boilers, and from time to time fresh pieces were added; carbonate of soda was also mixed with the feed water in regular doses: but all to no purpose, the action went on getting worse and worse.

No other alternative was therefore left, nor is there at present any other as far as the writer has been able to learn, but to feed the boilers with a portion of salt water sufficient to keep a thin incrustation over the surface of the iron. It was suggested that the deposit was nothing else than rust or oxide of iron, and that it was formed by the

chlorine present in the small proportion of salt water, which would combine with the iron to form chloride of iron; and this being readily decomposed by oxygen, oxide of iron would result. The difficulty here however was to know whence the oxygen was obtained; for the quantity of air entering with the feed water must have been very small indeed. It was also suggested that hydrochloric acid might be present from the small quantity of sea water that may have found its way into the boilers; but then the difficulty was to know where a quantity of the acid was to come from sufficient to act over such an extended surface, and so rapidly as the results showed.

It was found however by Mr. Rollo, one of the writer's partners, that in a pair of boilers at a sugar refinery there was the same brownish deposit adhering all over the boilers, and those parts subjected to the greatest heat were "pitted" in precisely the same manner as the second lot of marine boilers previously designated by the letter B. Exactly the same effects were being produced. These boilers were supplied with the same water over and over again, a small quantity of fresh water being added from time to time to make up for the loss. As the steam was passed only through iron pipes for melting the sugar, the damage to the boilers could not result either from the steam coming in contact with a soft metal, or from any lubricating material. The boilers were of the Cornish construction with one flue, and were worked at about the same pressure as the marine boilers B already referred to, say 20 lbs. per square inch pressure. A pair of boilers of exactly the same construction, placed alongside the first pair and working at about the same pressure, but fed with water which had not been distilled, were then examined to learn what state they were in. But although put in about the same time as the two first examined, these boilers were found in good condition and likely to last for years, as there was not a sign of corrosion or "pitting;" whereas the two boilers working with distilled water had to be repaired.

The practical knowledge thus acquired necessarily led to the conclusion that the distilled water itself was the cause of the corrosion, instead of any galvanic action or any fatty acid. In reference to the

question whether distilled water has any particular action on metals, the chemist Berthier found that nodular protuberances deposited on iron pipes containing distilled water consisted of 21 per cent. of protoxide of iron, 58 per cent. of peroxide of iron, 5 per cent. of carbonic acid, 14½ per cent. of water, and 1½ per cent. of silica. The iron pipes contained also a pulverulent substance, which could be produced at pleasure with distilled water to which a trace of carbonate of soda and common salt had been added, but not with an addition of caustic alkali. Distilled water is known to act powerfully on lead, and this action is attributed by Dr. Clark to the remarkable property that distilled water has, as compared with ordinary water, of dissolving free carbonic acid.

The writer does not presume to state confidently that distilled water is really itself the active destroyer of iron boilers; but, from the observations that have now been referred to and the information he has been enabled to obtain, he thinks there is sufficient evidence that distilled water is, if not the sole cause, at least an active agent in producing the corrosive effects that have been described. If this suggestion should lead to the remedy of the evils that have been experienced where distilled water alone has been used, another difficulty will have been overcome towards the complete introduction of surface condensers.

Mr. J. Ramsbottom said he had been much interested in the paper just read, and the conclusions arrived at coincided with the results of his own experience with stationary and locomotive engines, not with distilled water indeed, but with peat water which was almost as pure as distilled water. He had been informed that the boiler of the winding engine which formerly worked the Woodhead Tunnel on the Sheffield and Manchester line was corroded through in a very short time, being fed exclusively with the peat water from the Yorkshire moors; and on putting down a second boiler in its place the precaution

was taken of mixing with the peat water a portion of water from one of the shafts, the result of which was that the corrosion was almost stopped, but an incrustation of deposit was then formed inside the boiler. In the same range of hills he found that the locomotives working the Huddersfield and Manchester line with almost pure water had their boilers corroded in the same way; and he had now adopted the plan of putting a portion of carbonate of lime in the tanks, to prevent the corrosion.

Mr. C. Markham had also found the use of nearly pure water injurious to boilers, and the evil effects continued until the interior of the boiler became sufficiently coated with calcareous matter to prevent the corrosion going on. The effect produced by using pure water in boilers that had previously been worked with water containing a great quantity of lime was very remarkable: some of the locomotives on the Midland Railway were supplied with water that contained much lime, causing a great deposit in the boilers; and when any of these engines were sent down to Sheffield, where the water came from the moors and was very pure, the effect of the change was that the deposit was speedily removed in large masses, and he had seen a barrowful of the calcareous matter removed and washed out of a locomotive boiler after it had worked for a single day with the Sheffield water. So long however as an incrustation of lime remained on the plates it had the advantage of protecting them from any injury by corrosion from purer water.

Mr. J. McF. Gray thought the "pitting" observed in the case of locomotive boilers working with pure water was due to the brass tubes used in the boilers: for on examining the pitted plates by the microscope he had detected a minute speck of brass in the centre of so many of the "pits" as he thought would warrant the conclusion that this was the cause of all the pitting, in consequence of the galvanic action produced by the particles of brass. The corrosion of the iron had accordingly been prevented in those cases by suspending a piece of zinc among the boiler tubes, which neutralised the action of the brass. The pitting had not been so extensive in the hottest plates of the boilers as in other parts, because at the hottest parts the ebullition of the water was more violent, so that there was less facility for the

particles of brass becoming deposited there upon the plates to cause the corrosive action. From the paper it appeared not to be expected that distilled water would be able to be used successfully in boilers: but if the difficulty arose merely from the water used being distilled water, it might easily be got over by aerating the water, since the only difference in distilled water was that it was not charged with air like ordinary water. The real objection he considered to surface condensation was that the same water was then used over and over again without change; and he thought this must be the reason of the corrosion observed in the boilers of sugar refineries, the steam being condensed over the surface of the evaporating pans, whereby the water became in course of time impregnated with particles of brass or copper from the pans and pipes, gradually accumulating in the unchanged water. In the sugar plantations of the West Indies, where there was a difficulty in getting fresh water and the same had to be used over and over again, the water was found to get sour, as it was termed, and became more and more injurious to iron the longer it was used without change. He therefore thought the corrosion observed was to be attributed to the specks of brass carried into the boiler by the water where there was surface condensation of the steam.

Mr. D. Rollo observed that the object of the paper was not to discourage the use of surface condensation, but to point out the difficulties that had been met with in its application, with a view to ascertaining how they could be removed. With regard to the boilers at the sugar refinery that had been referred to, the corrosion could not he thought have been caused in that case by the presence of brass particles in the water; for the steam passed only between the two cast iron plates of the evaporating pans, and when condensed returned again to the boiler, without coming in contact with any brass at all in the apparatus, the leakage being made up by the addition of a little fresh water. There were four boilers all working together, two fed with the distilled water returned from the evaporating pans and two with fresh water: the two latter at the time of examination were found in perfect condition after four years' work, having only a large deposit or scale of lime over the surface of the iron; while the other two fed with the distilled water, after the same time of

working, had become quite unsafe from corrosion and had to be very extensively repaired. They had tried various remedies for the evil: suspending zinc plates in the boilers, but with what result had not yet been ascertained; cast iron pipes instead of copper pipes for conveying the steam; and tinned tubes, zinc, and galvanised iron tubes in the condensers, instead of brass. Block tin tubes had also been tried, but were found not to have strength enough to support their own weight when placed horizontally. All these trials therefore still left the question of the cause of corrosion undecided: but he thought it could not be the action of copper, because the analysis that had been made of the deposit found in the boilers using surface condensers showed a very small proportion of copper, the main metallic ingredient being iron, and there was not sufficient copper collected from the boilers in the voyage of a steamship to account for such an extent of corrosion as was met with. Where much grease however was used in the engine he had seen the inside of a boiler present an appearance which he thought rendered it just possible that the fatty matter or acids contained in the grease had something to do with deteriorating the quality of the water and causing its corrosive action.

Mr. H. W. Harman thought the pitting of the iron plates of boilers was not to be attributed to the presence of brass or copper tubes in the boilers, because he had known the pitting as a common occurrence and extremely marked where the boilers were entirely of iron and there was no brass or copper near, so that no particles of those metals could have got deposited in the boiler. In the immediate neighbourhood of Manchester he had seen examples of extensive pitting near the surface of the water in the interior of boilers using the town water; and it was remarkable that in some cases the alternate plates only were pitted, while the intermediate ones remained altogether untouched.

Mr. I. Smith concurred in considering the corrosion could not be solely dependent on the presence of brass or copper in boilers. About ten years ago he had erected a hot water warming apparatus at a house near Birmingham; and three or four years afterwards, on taking up the pipes in order to extend the circuit to another place, he found the whole of the wrought iron pipes gradually corroding away and lined

inside with a thin layer of black oxide of iron, though the cast iron pipes were not injured at all. In this case not a particle of brass or copper pipe was employed in any way about the apparatus, but the boiler was fed with rain water collected in the country and therefore nearly pure. The boiler was then emptied, and refilled with pump water containing a little carbonate and sulphate of lime; and on examining the apparatus again two years later he found that no more corrosion had taken place. At Messrs. Mason and Elkington's copper works at Pembrey in South Wales they had recently erected a surface condenser with cast iron pipes of 4 inches bore, and the boilers were fed with brackish pit water close to the sea, but not altogether salt. There was no brass or copper near the condenser or boilers, except the brass steam valves, the water valves being all of iron; and he should look with much interest for the results after the surface condenser had been at work for some length of time.

Mr. G. A. Everitt stated that two years ago he had made a large quantity of brass tubes for surface condensers of marine engines, and some time afterwards a large proportion of the iron tubes from the boilers belonging to them were shown to him, not only pitted but actually eaten through in large holes, which was attributed to the condensers having contained brass tubes. He believed this to be a mistake however, and that it was not the use of brass tubes in the condensers which caused the corrosion; and he enquired therefore whether the boilers referred to in the paper now read were ordinary flue boilers or boilers with tubes. The metal best adapted for the tubes of surface condensers did not appear to have been yet determined upon: brass had been used for a considerable time, and copper was now being tried. Experiments were also being made with electro-plated tubes, but these were so very expensive that they were not likely to come into general use: and brass tubes coated with tin had been tried, but were also expensive. Block tin and zinc tubes he had found did not keep straight when placed horizontally, as had been already mentioned; and white metal tubes were difficult to produce hard enough for the purpose: in fact it was difficult to produce any tubes so hard as the brass tubes, and at present the question appeared to lie mainly between brass tubes and copper tubes. The subject was

daily becoming one of wider importance, and he considered the writer of the paper had done much service in bringing forward the results of his own experience with surface condensers.

Mr. J. Kennan asked whether any experience had been obtained from the use of surface condensers with boilers having steel tubes, as to whether the steel boiler tubes were injured by the water in the same way as the iron boiler plates. He thought it appeared not unlikely that steel boiler tubes might be exempted from the corrosion: for where the iron plates were coated with a hard crust of lime the injurious action was retarded, and therefore it seemed probable that at the temperature of the water in the boiler the carbon contained in the steel might protect it similarly from injury.

Mr. E. Reynolds observed that in the discussion upon surface condensers at the London meeting of the Institution last year it was pointed out that the corrosive action on the boiler plates was possibly owing to the grease brought over into the boiler by the steam condensed from the engine, where surface condensers were used; and that it was necessary to change the water in the boiler frequently, in order to prevent this injury. The pitting of the boiler plates had been observed in the earliest instances of using surface condensers, and was the first cause for abandoning surface condensation, and there was also the objection that the boilers were more liable to prime: he understood it had been found that in some of the marine engines fitted with surface condensers the boilers were now liable to prime very much, but he was not aware whether this was to be attributed to the surface condensers. It had been shown he believed by Mr. Grove that the act of boiling ordinary water was not merely the conversion of that water into steam, but that the bubbles of steam appeared to consist of some well-defined free gas, frequently pure nitrogen from the air contained in the water, surrounded by an envelope of steam: hence when the same water was constantly returned to the boiler and repeatedly boiled, it might be expected to become changed in the course of time and might lose its original innocuous character.

Mr. D. Rollo explained that in all the vessels they had fitted up with surface condensers, more than 25 in number, the boilers had been tubular boilers, all with iron tubes, excepting only one or two

cases where brass boiler tubes were used; and in all cases the condenser tubes were brass. With regard to steel boiler tubes he had seen them tried and with no better results than the iron tubes; indeed in some instances they became corroded rather quicker than iron tubes, but whether that was owing to the additional carbon contained in the steel he could not say. He was satisfied however that priming had nothing to do with the use of surface condensers; because in no case had they had to make any alteration in the boilers after applying the surface condensers, nor had the priming ever been found to be worse after the surface condensers were applied than it had before been with the jet condensers previously used with the same boilers. If the boilers had plenty of steam room, he had found there was not any danger of priming; but if that point were neglected and the roof of the boiler were low, water would get carried over into the cylinders along with the steam. In support of the theory that the water underwent some change by the repeated boiling where surface condensers were used, he understood it was found that fresh water after continued use in that way carried the salinometer higher than salt water, showing that it had then become denser than the salt water used in marine boilers was generally allowed to get before changing.

Mr. B. Poole said they had made experiments with fresh water instead of salt in the marine boilers of the Wallasey ferry boats, and found it very successful in conjunction with surface condensers; and he could confirm the statement made as to the greater density of the fresh water after continued working.

Rev. A. Rigg remarked that where priming was observed in connexion with surface condensers it might probably be explained by the greatly increased coherence of the particles of distilled water, owing to the expulsion of the air contained in it by evaporation in the process of distillation, in consequence of which it was well known that distilled water boiled with great violence. In regard to the corrosive action accompanying surface condensation, there seemed reason to think that particles of the water might become decomposed in contact with the iron boiler plates into the constituent gases, whereby the iron would be oxidised without any action of brass

or grease or any other foreign matter contained in the water: and the remedy would then be merely to devise a means of coating the surface of the iron so as to prevent its oxidation, as it was found the corrosion did not occur where the iron plates were protected by a layer of deposit.

Mr. J. Mackay suggested that, as the corrosion attending the use of surface condensers was more rapid he believed on cast iron than on wrought iron, a heating apparatus of cast iron pipes might be attached to boilers working with surface condensers, for heating the feed water; and then any particles of brass or copper coming from the condenser would be deposited in the heating apparatus, and any other corrosive properties of the water would be expended on the cast iron pipes: thus the injurious effects of the distilled water would be mainly confined to the heating apparatus, and the boiler would consequently last longer. Moreover the durability of a boiler was affected by the position at which the feed water was introduced, and if the feed were at a place where the water was comparatively still the boiler would not suffer so much from corrosion or from deposit; and where the heat was properly distributed, so that one part of the boiler should not be hotter than others, a boiler would stand longer without injury. He knew of a boiler in a steamer that had been working for more than eleven years with a jet condenser, and the plates and tubes were still in almost perfect condition, in consequence of observing these precautions. Where there was any brass or copper for the steam or water to come in contact with, he thought there could be no doubt that particles of these metals must get carried into the boiler by the water, unless they were arrested on the way by some such plan as the feed-heating apparatus he had referred to.

The Chairman remarked that there seemed to be two theories suggested to account for the corrosion experienced in boilers working with surface condensers: first that a certain galvanic action was produced by particles of brass or copper carried into the boiler by the water from the condenser tubes, whereby the plates were corroded wherever a particle of those metals was deposited; and secondly that acids produced from the grease brought over from the engine might

have the deleterious effects that were noticed. In favour of the former theory, that the galvanic action occasioned by brass or copper caused the injury, was the peculiar shape which the corrosion assumed: it was not shown by a regular thinning of the plates, but they were pitted in particular spots, whilst the iron in the immediate neighbourhood was as thick and as good as ever; whereas if some acid had been acting on the plates it would be expected that the action must have been more uniform, and extended over the whole surface, instead of being concentrated at particular points. If the use of brass or copper tubes in the surface condensers had been the cause of corrosion, he suggested that the plan of Mr. Lamb's boilers, with a number of flat flues of iron plates exposing a large extent of surface, might be efficient for surface condensers also, to avoid having any brass or copper at all in their construction. He had himself experienced corrosive action in a number of boilers which had no brass work about them except the steam valves and valve boxes, and on certain portions of the iron plates a corrosion took place exactly like what had been experienced in the cases already described. One boiler in particular was attacked out of a set of 25, and for a considerable time the corrosion could not be accounted for. The corroded iron plates were removed and steel plates substituted for them, but these also were eaten away and pitted exactly in the same manner. Then the water was changed, and fresh water was used from the town supply or from a well; this was constantly changed, so as not to use the same water over and over again, and new steel plates were put in to replace the corroded ones. In this case no amount of acid could be formed from grease, because there was no grease that could get near the boiler, except a little oil to keep the donkey pumps lubricated. The remedy was then found to lie in altering the manner in which the feed water was injected. The boiler was a vertical one, 30 feet high, with two large flues through it, and the feed water was originally injected at the bottom, impinging upon the flue; and the pitting of the plates took place for a length of 3 feet from the entrance of the feed. But by altering the feed pipe to enter at the centre of the boiler and furnishing it with a rose jet to distribute the feed water gradually, the corrosion was completely stopped at once. He enquired whether it had

been found that there was any particular way of supplying the feed water in the boilers described in the paper, in order to diminish the corrosive effects.

Mr. D. Rollo replied that he had not found that the place where the feed was introduced in the boilers had any perceptible connexion with the corrosion: the feed pipes had been altered to different positions in several of the boilers described in the paper, and in some had remained unaltered, but without affecting the corrosion; and the corrosive action seemed to have no special effect at the parts nearest the entrance of the feed, but the pitting seized upon one plate and another indiscriminately and with considerable spaces between. Priming no doubt was affected by the position of the feed entrance; and in one of the vessels that they had fitted with the surface condensers, having round tubular boilers, much trouble had been experienced from priming, in consequence of the feed being injected too near the point where the steam was taken off; but by putting the feed pipe lower and at the back of the boiler, the priming was now got rid of completely. He did not think the corrosion of the boiler plates was caused by grease contained in the water: but it seemed more probable that by constantly boiling the same water over and over again it was robbed of some of its original properties, or became otherwise altered in quality thereby, so as to produce the serious effects that were experienced.

The Chairman moved a vote of thanks to Mr. Jack for his paper, and also to Mr. Rollo, which was passed.

The following paper, communicated through Mr. William Clay, was then read:—

ON THE MECHANICAL FEATURES OF THE LIVERPOOL WATER WORKS.

By Mr. THOMAS DUNCAN, of Liverpool.

The question of providing a supply of water for large towns has always been one of deep interest and importance, and must continue to be so. It may safely be stated that within the last quarter of a century a greater amount of mechanical skill has been devoted to the improvement of water supply than during any previous period of equal duration, especially in this country; and although much that was known and practised before has only been modified or in some instances improved, still a good deal that is comparatively new has been introduced.

In the Liverpool Water Works, forming the subject of the present paper, the supply is partly by gravitation and partly by pumping. The area over which the supply is distributed is nearly 60 square miles, and contains about 600,000 inhabitants. The gravitation portion, designed chiefly by Mr. Hawksley, is the largest although not the oldest, and has its origin amongst the hills lying between Blackburn and Bolton; the upper portion is distant in a direct line from Liverpool about 30 miles. The area from which the water is collected extends to 10,000 acres, and the greatest altitude is 1700 feet above the ordnance datum or mean low water level. The formations from which the water is obtained are the lower beds of the coal measures and the millstone grit. The average rainfall is nearly 46 inches per annum, and the quantity collected is about 75 per cent. of the total rainfall.

The general plan, Fig. 1, Plate 44, shows the positions of the several reservoirs, and the course of the pipe line throughout the entire length of the works. Fig. 2 is a vertical section taken along the course of the pipe. The principal reservoirs, shown black in Figs. 1

and 2, are formed in the valleys by embankments thrown across them, intercepting at various levels the streams which flow from the hills. The highest reservoir, the Upper Roddlesworth, is now in process of formation; and immediately below it are the Lower Roddlesworth and the Rake Brook reservoirs. From these the water is conveyed by a "goit" or open cutting down to the Anglezark and Rivington reservoirs, whence it passes to the filter beds at Horwich. The first portion of the works may be considered as terminating at this point. From Horwich the water is carried to Liverpool through a line of cast iron pipes of 44 inches diameter, broken by a short tunnel less than a mile long, and by the three balancing reservoirs at elevated points along the line—Aspull, Montrey House, and Prescot—the last being about 7 miles distant from the borough. The water is finally conveyed into the various home reservoirs for distribution. The area of the several reservoirs amounts to more than 500 acres, and the quantity of water contained in them when full is 3,000,000,000 gallons. At present about 12,000,000 gallons per day are filtered and distributed in Liverpool and the vicinity from Rivington.

The mechanical appliances connected with the gravitation portion of the works are as follow :—

1.—Slide valves in the embankments.
2.—Sluices and floodgates on the open cutting or goit.
3.—Self-acting gauges on the goit.
4.—Filter beds.
5.—Sand washing apparatus.
6.—Float valve at upper end of tunnel.
7.—Self-acting shut-off valves in the reservoirs.
8.—Reflux valves in the reservoirs.
9.—Self-acting throttle valves in the main.
10.—Escape valves on the main.
11.—Stop valves, scouring valves, and air cocks.
12.—Main or pipe line.

1. *Slide Valves.*—These are of the ordinary description. The casing is of cast iron, fitted with planed joints; and the screw spindle is of brass, working through a nut attached to the slide; a brass face is pinned on the slide, working against a brass ring pinned on the

framing. These valves are placed under all the embankments in double pairs, the spindles being fitted with stuffing-boxes and carried up through guides in the shafts, so as to be worked from the top of the embankments. The valves are nearly alike in size and character in all the embankments.

2. *Sluices on the Goit.*—Near the Rake Brook reservoir there are a pair of 3 feet square sluices on the goit, working in cast iron frames and moved by a screw spindle, bevil gearing, and crank handle. One man can shut and open these easily with a head of 12 feet on the sluices. At Brinscall Hall works there are sluices, placed in frames built in the masonry, worked in slides by rack and pinion motion, in order to allow of passing away by the original brook course such a quantity of water as will relieve the goit in time of high flood. Again at White Coppice, where the Black Brook falls into the goit, a set of three sluices are placed, worked by a screw motion. The water of the Black Brook can be caused to flow either into the goit, or over it through a wrought iron trough, as may be found desirable; and thus the water can be rejected if unsuitable, or if it be necessary to relieve the cutting in time of flood, as at Brinscall Hall.

3. *Self-acting Gauges on the Goit.*—There are two sets of these gauges on the course of the goit, one at Brinscall Row and the other at White Coppice, provided for measuring off compensation water to mill owners, giving off a stipulated quantity of water day by day. Figs. 3 and 4, Plate 45, show longitudinal and transverse sections of the gauge. It consists of a cistern fitted with inlet pipe A from the goit and outlet orifice B of notch form, as shown enlarged to one quarter full size in Fig. 5: a brass plate is fixed on the inside of the cistern with a thin-edged aperture of the exact size required, so as to give off always the same delivery of water from the cistern with great accuracy. A beam is placed over the cistern, supported on a cast iron frame, having a stone float C attached to one end and a vertical loaded copper cylinder D to the other, both adjusted by screws: the top of the cylinder D is above the high water level in the goit, and the bottom is faced to match the end of the inlet pipe A from the goit. By this arrangement the area of passage at the bottom of the cylinder D is constantly regulated by the float C to correspond with

the area of the outlet opening B, thereby providing with ordinary care for a constant quantity of water flowing off through the gauge. These gauges have been in use for about four years, and have given no trouble beyond oiling and cleaning, and have uniformly acted well. The relative levels of the gauge and goit are so adjusted that if there is any water flowing along the goit the gauge must be supplied before any portion of the water can pass further down the goit.

4. *Filter Beds.*—There are six filter beds, each 300 feet long and 100 feet wide, constructed in the following manner. The bodies of the beds are part in excavation and part in embankment, and about 10 feet deep. At the bottom of each bed are a pair of dry rubble drains, above and around which is placed a quantity of broken stone varying from 4 inch pieces down to 2 inches cube; above this five layers of gravel are laid varying in size from 1 inch to about the size of peas. On the top of the gravel is a layer of sand 30 inches deep. The water is admitted upon the filter beds by drains regulated by stop planks, and passes down through the sand and gravel into the drains at the bottom. Four air pipes are inserted into each filter over the drains, to prevent the accumulation of air; these are cast with slots in the side, over which copper wire gauze is fastened to prevent the sand passing into the pipes. The two drains under each filter bed unite together into one, and deliver the filtered water into a pit, from which a pipe communicates with the clear-water tank. On the end of the pipe within the pit a sluice is placed, worked by a screw spindle carried up to the surface; so that any filter bed may be shut off at pleasure, or all may be in work together. There are two clear-water tanks, extending lengthways across the ends of the six filter beds, with an inlet from each bed. They contain together 12 million gallons when full, and are constructed with the bottom slightly inclined towards a cleansing outlet, and sloping sides, and are paved with dressed stone. The main pipe conveying the water to Liverpool is inserted into these tanks, one branch into each, fitted with sluices, so that either of the tanks may be worked by itself or both may be used at the same time.

Any solid matter in suspension in the water is intercepted and retained at the upper surface of the sand in the filters. When any of the filter beds becomes foul and the requisite quantity of water will not pass,

the supply of water is shut off from that filter and the water in the clear-water tank is lowered below the surface of the sand in the bed; the upper film of sand, generally about ¾ inch thick, is then removed and washed, and when a sufficient quantity of clean sand is prepared and the filter cleared, the sand is put on again, and the filter thus restored to its original condition. The length of time a filter will work before requiring cleaning depends altogether on the quantity of matter in suspension in the water, coupled with the quantity of water which has passed through the filter. Sometimes the filters have worked for six weeks, at other times they have not worked for more than ten days, and on a few occasions not for more than a week: fourteen days may however be taken as a mean, and the annual cost at £100 for every million gallons filtered daily. This sum provides for replacing the sand lost in the process of washing, where it does not cost more than 6*s.* per cubic yard laid on the works. The mean quantity of water which will pass through one of the Rivington filters may be taken at half a cubic foot per hour for every square foot of surface.

5. *Sand Washing Apparatus.*—The sand washing is performed by machinery, consisting of a nearly horizontal spindle with a number of spiral blades upon it, placed in a trough 12 feet long, and driven by a small high pressure horizontal engine. A stream of clear water flows into the upper end of the trough, and the foul sand is carted into a hopper at the lower end, from which it is fed into the trough by a screw driven by the engine. The screw blades on the longitudinal spindle then carry the sand forwards against the stream of water to the upper end of the trough, where it is caught by scrapers placed on an endless revolving gutta-percha belt; this works in an inclined trough and carries the washed sand upwards until it falls into shoots at the top, which convey it into wagons to be removed for use again in the filters. The head gearing on the top of the shoots is provided with extension gearing by which any lengthening of the gutta-percha belt can be taken up; and the shoots are arranged to shut or open as required, so that no sand may fall while a full wagon is being taken away and an empty one placed under them. Ten cubic yards of sand per hour are washed and loaded into carts by this machine. The idea of this machine was obtained from a small one at Crewe, designed and

constructed by Mr. Ramsbottom; the arrangements for self-feeding and loading the washed sand have here been added to the original.

6. *Float Valve at upper end of tunnel.*—The main or pipe line commencing in the clear-water tanks passes across the valley and under the Bolton and Preston Railway, and then enters a hill distant about 2 miles from the filtering works. At this point it terminates in a circular tank of brickwork at the upper end of the tunnel, into which the water is delivered, as shown in Figs. 6 and 7, Plate 46. The pipe is fitted with a sloping end piece E, on which is hinged a flap valve F, shown black in Fig. 6. When any stoppage takes place on the down-stream side, the water rises in the tank, and the floats G rise, and by means of the levers H close the flap valve F and shut back the water in the supply pipe E; until the water again falls on the lower side, when the floats fall and open the valve again, as shown dotted in Fig. 6, allowing the water to run free as before. The brick tunnel about 1600 yards long is succeeded by about a mile of pipe, which carries the water to Aspull reservoir, where it is delivered. Aspull and Montrey House reservoirs may be considered simply as relieving reservoirs.

7. *Self-acting Shut-Off Valves.*—On the outlet pipe from the various reservoirs a self-acting shut-off valve is placed, which is shown in Figs. 8 and 10, Plate 47, for shutting off the flow of water from the reservoir when a fracture takes place on the pipe line on the delivery side. The outlet pipe K has an up-turned end, fitted with a brass face, over which is suspended vertically the cylindrical valve L of the same diameter, with a brass face on the bottom, fitting the face of the pipe K. In the outlet pipe is hung a flat disc I, Figs. 8 and 9, at the end of a long lever, presenting its flat face to the current of water flowing off from the reservoir, and weighted by the weight J so as to stand still as long as the water flows through the pipe at the proper velocity. But whenever a fracture takes place on the delivery side of the pipe, the current is accelerated, and the disc I is thereby thrown forwards, as shown dotted in Fig. 8; the trigger M is thus released and thrown off, and the large suspended cylinder L descends on the orifice of the pipe K, shutting off all further passage of the water down the pipe. Alarum bells connected with the valves have recently been

fitted to each of the cottages at the reservoirs where these valves are placed, so that if the valve runs down the bell is rung to warn the keeper.

8. *Reflux Valves.*—At each of the reservoirs there is a reflux valve placed on the end of the inlet pipe supplying the water to the reservoir. This is shown in Figs. 11 to 13, Plate 48, and consists of a series of hinged doors or flaps N with brass faces, hung on the orifice of the inlet pipe, which has also brass faces slightly inclined to the vertical. The current of the water entering the reservoir keeps the flaps sufficiently open to admit the water to pass in; but whenever a fracture occurs at a point on the up-stream side lower than the water in the reservoir, the weight of the valves and the pressure of the water closes them, and so prevents a reflux of the water from the reservoir.

The above description applies to all the self-acting apparatus fitted to the reservoirs, and the only other mechanical appliance in connexion with them is the delivery well at the Prescot reservoir. This is a circular iron tank, into which the main pipe delivers the water, with a reflux valve fitted on its extremity. From this well the water is conducted into the different compartments of the reservoir by pi es furnished with slide valves, which are worked by screw spindles and bevil gearing. Any portion or all of the pipes may thus be shut off, or all the communications can be open together. An overflow pipe rises in the centre of the well, communicating with an overflow culvert carried from the well, so that any excess of water is permitted to pass away without injury to the embankments. A series of observations have been carried over many months, taken at fixed periods daily, carefully noted and compared with actual measurements of the quantity of water passing through the main between Prescot and Liverpool; so that by observing the point at which the weight stands on the lever of the self-acting valve, the quantity of water delivered can be computed and ascertained exactly.

9. *Self-acting Throttle Valves in the Main.*—One of these valves is shown in Figs. 14 to 17, Plates 49 and 50, and they are designed for a purpose analogous to that of the self-acting shut-off valves placed on the reservoir outlets, but differ considerably in construction. The throttle valve O, Figs. 14 and 16, is placed on a horizontal spindle in

the main, and on the outer end of the spindle is a wheel P carrying a heavy weight, which tends to close the throttle valve O, but is prevented from doing so by the trigger M catching the stop on the wheel P. A flat disc I, about 18 inches diameter, Figs. 16 and 17, is held in the main at the end of a long horizontal lever, presenting its flat face against the current; and as long as the velocity of the current does not exceed the proper limit, the disc is held stationary in its place by the weight J, as shown in Figs. 14 and 16, the vertical spindle on which the disc lever I is carried being geared by toothed sectors to the spindle of the weight lever J; and the throttle valve O then stands full open, presenting its edge to the stream, as shown by the dotted black line in Fig. 14. When a fracture takes place on the down-stream side, the velocity of the current along the main is increased, the disc I is pressed forwards, as shown in Fig. 15, the trigger M is released, and the weight on the wheel P of the throttle valve spindle descends, turning the throttle valve O across the main, as shown by the dotted black line in Fig. 15, and thereby entirely stopping the passage of the water. The spindle of the throttle valve is placed 1½ inch out of the centre of the valve, so that the pressure of the water may assist the weight in closing the valve. In order to prevent the throttle valve from closing suddenly, and thereby causing an injurious concussion upon the main by the sudden stoppage of the long column of water, its motion in closing is retarded by a piston working in a small water cylinder Q, the piston rod being connected to the wheel P on the throttle valve spindle. A small pipe communicates from the top of the cylinder Q to the small cistern R on the top of the main, and a second pipe from the bottom of the cylinder to the cistern; in the first of these a stopcock S is placed, worked by a lever T; and as the wheel P turns round, closing the throttle valve O, a stud on the wheel raises the lever T and gradually closes the stopcock S, as shown in Fig. 15, so that the discharge outlet from the cylinder Q is throttled, and the closing of the throttle valve O retarded. When the valve O has to be opened again, the small hand force pump U connected with the cistern R is used to force the piston down to the bottom of the cylinder Q, thereby turning back the wheel P into its original position and opening the throttle valve O; the delivery pipe from the force

pump enters below the stopcock S, which is kept closed until the opening of the valve O is complĕted, when the whole apparatus is set again in its original working position. Owing to the use of the retarding cylinder Q and stopcock S, about three minutes are occupied in shutting the throttle valve O. These self-acting throttle valves were furnished by Sir W. G. Armstrong and Co. of the Elswick Works.

10. *Escape Valves on the Main.*—However slowly the current in a large main is stopped, there will always be practically a series of pulsations running backwards to the fountain head from which the water is supplied, their intensity depending on the velocity at which the water was moving when the stoppage was commenced and on the length of time occupied in arresting the current. To obviate the danger arising from this cause, loaded escape valves have been placed along the line of main and behind the self-acting throttle valves, as shown in Figs. 18 and 19, Plate 51. These are loaded slightly over the working pressure in the main, and communicate with some convenient water course; so that when the current is stopped by the closing of the throttle valve the escape valve is lifted as soon as the recoil reaches it, an escape of some water takes place, and so on at every pulsation, until the force of the recoil falls within the limit to which the valve has been loaded over the working pressure, whereby all danger to the main is prevented.

11. *Stop Valves, Scouring Valves, and Air Cocks.*—At various points along the main are placed stop valves, so that the water may be shut off at convenient distances for facilitating repairs. They are slide valves formed with three vertical slides, the largest in the centre, and a smaller one on each side, worked by screw spindles. A scouring outlet closed by a slide valve is also placed at each brook course or hollow where practicable, by which the pipes may be scoured out whenever necessary. On each summit along the course of the main a small air cock is inserted into it to allow the air to escape. These are simple stopcocks, with short lengths of lead pipe attached to carry off the waste water from them. It has been found advantageous to leave them slightly open, sufficiently to permit a small quantity of water to escape; this ensures a full main.

12. *Main or Pipe Line.*—The main is 44 inches internal diameter, and is for its length the largest main yet laid. The pipes are jointed in the ordinary manner with yarn V and lead W, as shown in the section, Fig. 20, Plate 51, one quarter full size; for the greatest portion of the length they are strengthened by wrought iron hoops shrunk on the sockets. Between Prescot and Green Lane an additional line of pipe is about to be laid of 36 inches diameter, with bored and turned joints, as shown at X in the section, Fig. 21, one quarter full size. These joints are bored and turned slightly conical, with a taper of about 1 in 62 on each side, and a single thread of tarred yarn is lapped round the spigot end to provide a slight elasticity in the joint; the pipes are then put together with melted asphalt Y, the socket being slightly warmed at the time for the purpose of expanding it when pressing the spigot end into its place. Experiments have been made in Glasgow, where these pipes are being cast, from which it is found that joints made in this manner resist a high pressure; and when the ground on which they are to be laid is solid, they are employed with considerable pecuniary advantages. Pipes with these joints have recently been laid at a saving of 50 per cent. in cost of laying over the ordinary plan of lead joints: and they have been used for water mains in Liverpool for several years past with perfect success. Several experiments have been made to ascertain the amount of deflection that may be safely obtained with pipes jointed with these bored and turned joints. Two pipes of 24 inches diameter were jointed in this manner, and flanges were bolted to the outer ends with holes for a pressure gauge and the pump connecting pipe. They were supported at the ends only, leaving a clear distance of 23 feet unsupported, and were then weighted with 36 cwts. on the centre, which produced a deflection of $\frac{1}{8}$ inch. A pressure of 190 lbs. per square inch was then applied by the pump, and the joint began to draw slowly, causing the pipe to sink in the centre. A deflection of 6 inches was obtained before there was any leakage, when the pressure was 160 lbs. per square inch, at which point a slight leakage commenced.

The line of 44 inch main terminates at Green Lane. At Old Swan one branch 24 inches diameter is taken off to the left, and carried to the Parkhill reservoir at the south end of the town. Another branch

24 inches diameter is carried along Green Lane to the reservoir at Audley Street for the north end. The main 44 inches diameter is reduced to 36 inches, and is carried into the Kensington reservoir. The reservoirs in town are all covered by brick arching grassed over; and from them the various distributing mains are carried.

The town is divided for the purpose of the water supply into three main divisions, north, middle, and south; and these three each into upper, middle, and lower levels. Each of these is again subdivided into sections, so that any one can be shut off without interfering with the others; and between each main division communications are made, so that they may be supplied in more than one way.

The old valves which belonged to the old water works have been nearly all removed and replaced by screw slide valves of the best make; and in nearly every instance the water supply to the several divisions is regulated by slide valves of the best kind. The connecting ferrules for the service pipes are screwed into the iron pipes, and the lead service pipes are attached without solder. Stopcocks of the best make are fixed on the service pipes in the footways to all new property, but much of the old property is still without this provision, and some years must elapse before the whole can be made uniform.

Wherever an intermittent supply of water has originally existed and a constant supply has subsequently been introduced, it has been found more difficult to reduce the quantity of water consumed to a minimum, than where the constant supply has been established in the first instance. This arises from the defective fittings pertaining to the old system, and the larger sized service pipes which were necessary to give such a supply as was given in Liverpool, namely three times per week and generally not for a longer period than 1½ hours at a time.

The hydrants for extinguishing fires now used in Liverpool are chiefly laid in the footways. They are simple slide valves with up-turned nozzles, and have screws to fit the fire hose. They are placed at convenient distances, generally in pairs, so that several sets of hydrants can be brought into play at a fire if necessary. In Liverpool engines are not generally used at fires, but the water is thrown direct from the hydrants fixed on the mains. Similar hydrants are laid

around all the docks, and are used for the supply of water for shipping. Meters mounted on spring carriages have recently been introduced for the shipping-service supplies. When a vessel is to be supplied with water, the waterman wheels the meter close to one of the hydrants, a short length of hose is attached to the hydrant and the meter, and another hose is carried from the outlet of the meter either on board the ship or to casks placed on the quay. The index is taken, the hydrant opened and the supply given, when the quantity supplied is read off the index and the charge adjusted accordingly. From four to five thousand gallons per hour can be supplied in this way by one meter, and all disputes as to the correct quantity of water delivered or the size of vessels to be filled are thereby obviated. The meters generally do not vary more on either side than one per cent. from the correct measurement. A meter with its carriage complete costs about £20; and the cost of their repairs, taking the experience of three years, is 1*s.* 6*d.* per million gallons delivered.

The flushing cocks or valves are similar in construction to the other slide valves already described. They are used for flushing the sewers, and are carried from the mains at those points where the greatest length of sewer can be flushed by a single cock. An eyelet is carried up to the surface immediately over the junction with the sewer, so that any escape may be seen on inspection from the surface. A peculiar kind of cap is placed over the spindles of these valves, so that they cannot be opened by mistake; such mistakes have occurred, but have been prevented since these caps have been employed.

Up to the commencement of 1857 all the water supplied to Liverpool was obtained from wells in and about the town, sunk in the new red sandstone, the formation of the district, from which the water was pumped by steam power. Immediately before the introduction of the water by gravitation there were seven pumping stations with wells and one pumping station from a reservoir. The wells varied in depth from 130 to 200 feet. There were in all eleven engines, ten of which were generally in work at a time; only a few of these need be noticed. The accompanying Table I appended gives the principal particulars of the engines and boilers. Table II shows the cost of pumping by

the various kinds of engines employed, taken over an entire year. Table III shows results obtained in testing the economic value of several kinds of Lancashire coal mixed with slack at the pumping stations, the water evaporated being measured by a meter.

At Green Lane station there are three engines. The first, by Harvey of Hayle, has been erected for sixteen years, and with short intervals of rest has been kept working ever since. The second, by Forrester and Co. of Liverpool, was erected in 1852, and has also been almost constantly at work since that time. The third was removed from Bootle Station, and after being thoroughly overhauled and repaired was put up in its present position in 1855, and has with the others been nearly constantly at work. The two first are Cornish engines, and the third a double-acting crank engine.

The pumps of the two Cornish engines are solid plungers working through stuffing-boxes. The lower plungers are worked by rods of flat bar-iron attached to crossheads at top and bottom. The length of stroke in each case is 8¾ feet, and the diameter 17¼ and 19 inches respectively. Each of the lower plungers delivers its water into a cast iron cistern a few feet below the surface of the ground, into which the wind-bore of the upper plunger dips. The delivery in the case of the first engine is directly into the ascending limb of a stand-pipe enclosed in the tower containing the chimney; and in the case of the second engine the delivery pipe is attached to the bottom of the descending limb, whence an 18 inch pipe passes to the 36 inch main from Rivington, in which both waters are mingled. To the first engine an auxiliary bucket lift is attached, of larger dimensions than the plunger pump; and in order to provide for getting down to the lower plunger it is constructed to deliver its water at the surface. The valves are all double-beat, the beats being now wholly composed of gutta-percha, which has been found to suit the purpose intended better than any other material that has been tried. The pump of the third or crank engine is a single-lift bucket pump working into an air vessel. The load on the upper plungers of the two Cornish engines is about 50 lbs. per square inch, and on the bucket of the third engine 120 lbs. per square inch. The indicator diagrams obtained from the two Cornish engines with 275 feet of lift are shown in

Figs. 22 and 23, Plate 52; and Fig. 24 shows the diagram from the crank engine with the same lift.

The boilers to these engines, three to each of the two Cornish engines and two to the crank engine, are cylindrical with internal flues. The draught is carried through the flues to the back, returning along the sides, uniting and returning to the back along the bottom, and then into the main chimney flue which extends across the ends of the boilers with dampers to each boiler and to the entrance into the chimney. Each set of boilers is provided with a steam chest; and all are enclosed in brickwork, a small clear space being left both between the boilers themselves and the steam chest, and the brickwork is levelled up and flagged over. The condensing water from the engines is passed through a set of cooling ponds, and with a slight supplementary supply from the wells is used over and over again.

The wells from which these engines work are 185 feet deep below the surface, and have tunnels or drifts extending in all about 300 feet from the shafts in various directions: three separate shafts are carried up to the surface. The quantity of water yielded by this well is greater than from any other of the wells of Liverpool, being more than three million gallons daily. A 9 inch diameter borehole has been sunk below the bottom of the well to a depth of 185 feet deeper, which largely increased the quantity of water yielded. The flow from the borehole is regulated by a plug at the bottom of a long rod working in guides, which is raised or lowered by a strong screw at the top, whereby the borehole is opened or shut at pleasure. In preparing for the seat of the pumps attached to the second engine a diving apparatus was employed, and all rubbish was cleared away from the bottom; thus the difficulty of obtaining a sound good job in fixing the pitwork was greatly diminished.

At Windsor station the pumps are arranged in two lifts, the bucket below and plunger above; the first delivers the water into a cistern, the second works from the cistern and into a column or pipe with the upper end closed, acting as an elongated air vessel, with which the distributing main is connected. Originally it was intended to supply a part of the town direct from this station, and in order to meet the varying load a balance bob with a weight was applied to

the engine. To remove this weight every time a change of load took place was found inconvenient, and a small line of rails with truck and screws was therefore placed over the balance bob pit, by which one man can in a few minutes make the required change. The boilers are plain cylindrical without flues, with steam chest on the top, all covered as at Green Lane. Originally much of the surface was left exposed, but now all is covered in, and the effect has been such a saving in fuel as in a short time repaid all the cost of the alterations. The condensing water is worked in a circuit through a small cooling pond, as at Green Lane. Figs. 26 and 27, Plate 53, show indicator diagrams taken from the engine at this station: Fig. 26 shows the diagram with 247 feet height of lift, and Fig. 27 is the diagram with 295 feet lift.

At Bootle station there are two old double-acting crank engines with double-acting pumps. Originally they were worked with low pressure steam; but the old wagon boilers have now been removed and replaced by tubular boilers covered over, and high pressure steam with a covered steam chest has been applied; the saving in fuel thus effected has been 30 per cent. Fig. 25, Plate 52, shows the indicator diagram obtained from one of these engines with 170 feet lift. The pumps work into air vessels, from which the mains are carried, supplying the district between the station and the reservoir; and the difference in quantity between supply and demand flows into the reservoir. The wells of Bootle yield about 800,000 gallons daily; they are about 50 feet deep. Some years ago several boreholes were sunk here, one to the depth of 600 feet below the bottom of one of the collecting wells; at first this yielded a large volume of water, but now it yields a very small quantity.

The other old pumping stations now seldom or never used are the Bush, William Henry Street, the Park, and Hotham Street. At all of these with one exception the engines were nearly alike, old and costly to work. There are two pumping stations besides, where there are no wells, but the water is raised for the supply of the high level district from reservoirs which supply the middle and low levels: these are Audley Street and Devonshire Place stations.

The Audley Street engine is Cornish, made by the Haigh Foundry Co., Wigan. The cylinder is 36 inches diameter, 6 feet

stroke in the cylinder and 6 feet stroke in the single plunger pump of 19 inches diameter, which draws from a cast iron well communicating with the lower reservoir. The water is raised 92 feet into a covered tank 75 feet diameter and 10 feet deep, containing a quarter of a million gallons nearly, from which the high levels are supplied. There are no internal ties in the tank, but it is supported entirely from without at about one third of its height by wrought iron hoops and struts from the ends of the supporting girders. Self-regulating gauges are attached to the clocks in the engine house, from which traced diagrams are daily obtained, showing the hour lines and the corresponding depths of the water at any time in both the tank and reservoir. Fig. 28, Plate 53, shows the indicator diagram obtained from this engine with 100 feet lift.

At Devonshire Place station there is a small high pressure engine, possessing no feature of interest and expensive in working, which will shortly be superseded by a second Cornish engine about to be put up at Audley Street. This is to have a 50 inch cylinder with 10 feet stroke, and 29 inch solid plunger; in its general features it will resemble the engine already erected at that station.

Besides the works already described there are two small reservoirs in progress near the town; one for receiving the water direct from the main from Prescot, and an engine is being made for pumping from a well in connexion with this reservoir into the second reservoir.

TABLE I.

Liverpool Water Works.

Particulars of Pumping Engines and Boilers.

Name of Engine.	Description of Engine.	Date of Erection.	Cylinder. Diam.	Cylinder. Stroke.	Pumps. Diam.	Pumps. Stroke.	Water raised per stroke.	Depth of Well.	Total Height of Lift.	Actual Horse power used.	Boilers. No.	Boilers. Length.	Boilers. Width.	Boilers. Description.
			Ins.	Ft. Ins.	Ins.	Ft. Ins.	Galls.	Feet.	Feet.	H. P.		Ft. Ins.	Ft. Ins.	
Green Lane No. 1	Cornish	1846	50	9 0	17¼	8 9	83	185	275	70	3 *c*	26 0	5 9	Cylindrical
„ No. 2	Do.	1852	52	9 0	19	8 8½	104	185	275	77	3 *d*	26 0	5 9	Do.
„ No. 3	Double-act. crank condens.	1837*a*	34	6 1	17	4 0	39	185	275	52	2 *d*	26 0	5 9	Do.
Windsor...........	Cornish	1840	50	9 0	16⅛	8 9	75	210	287	62	4	33 0	5 0	Do.
Bootle No. 1	Double-act. crank condens.	1821	34	6 0	16½	3 9	31	50	170	28 (Nos. 1 and 2)	5 *e* (Nos. 1 and 2)	25 0 (Nos. 1 and 2)	6 3 (Nos. 1 and 2)	Wagon (Nos. 1 and 2)
„ No. 2	Do. do. ...	1814	31	6 0	16½	3 9	31	50	170					
Audley Street ...	Cornish	1857	36	6 2	19	6 2	74	20 *b*	100	...	2 *f*	20 0	6 6	Cylindrical
Devonshire Place	Double-act. crank non-cond.	1833	14¼	6 0	15⅝	4 0	31	20 *b*	106	17	2	20 0	5 0	Do.
Bush	Single-acting condensing ...	1801	38	6 0	11½	5 9	21	149	228	16	2	18 5 / 21 0	7 9 / 6 0	Wagon / Horseshoe
Soho	Double-act. crank condens.	1825	30	6 0	9 / 10	3 11 / 4 9	34	123	247	27	2	21 7½ / 22 0	7 0 / 6 9	Wagon
Hotham Street ...	Do. do. ...	1801	27	5 0	8⅝	3 4½	15	110	205	12	1	19 0	6 2½	Do.
Water Street	Do. do. ...	1827	30	6 0	12½	3 11	19	156	257	24	2	30 0 / 24 0	6 6 / 8 0	Cylind. *g* / Wagon

a, transferred from Bootle 1855. *b*, these engines pump from reservoirs. *c*, 3 ft. 6 ins. fireboxes with four 13 ins. flues. *d*, 3 ft. 6 ins. fireboxes with three 14 ins. flues. *e*, these were all old boilers of which three only were worked at a time; they have now been removed and replaced by cylindrical boilers like those at Green Lane. *f*, 3 ft. 10 ins. fireboxes with three 14 ins. flues. *g*, with one 3 ft. 10 ins. flue.

TABLE II.

Liverpool Water Works.

Cost of Pumping at the several stations.

Pumping Stations.	Total Height of Lift.	Total Water pumped in year.	Cost of Coal. Total in year.	Cost of Coal. Per million gallons.	Cost of Coal. Per 1000 gals.	Cost of Stores. Total in year.	Cost of Stores. Per million gallons.	Cost of Stores. Per 1000 gals.	Establishment Wages. Total in year.	Establishment Wages. Per million gallons.	Establishment Wages. Per 1000 gals.	Cost of Repairs. Total in year.	Cost of Repairs. Per million gallons.	Cost of Repairs. Per 1000 gals.	Total Cost. Total in year.	Total Cost. Per million gallons.	Total Cost. Per 1000 gals.	Total Cost per mill. gals. per 100 feet of lift.
	Ft.	Gallons.	£ s. d.	£ s. d.	d.	£ s. d.	s. d.	d.	£ s. d.	£ s. d.	d.	£ s. d.	s. d.	d.	£ s. d.	£ s. d.	d.	£ s. d.
Green Lane	275	1,065,161,241	1319 19 0	1 4 9	·297	219 19 1	4 2	·050	538 5 2	0 10 1	·121	405 16 10*	7 7	·091	2484 0 1	2 6 7	0·559	0 16 11
Windsor	287	374,310,750	452 8 2	1 4 2	·290	86 2 3	4 7	·055	278 4 2	0 14 10	·178	105 1 9	5 7	·067	921 16 4	2 9 2	0·590	0 17 2
Bootle	170	282,240,120	536 11 9	1 17 4	·448	92 1 1	6 6	·078	284 6 11	1 0 1	·241	73 2 11	5 2	·062	986 2 8	3 9 1	0·829	2 0 8
Audley Street and Devonshire Place	106	176,384,730	328 19 7	1 17 3	·447	23 1 10	2 7	·031	154 9 3	0 17 6	·210	40 11 2	4 6	·054	547 1 10	3 1 10	0·742	2 18 4
Bush	228	98,402,304	337 18 9	3 8 8	·824	25 17 2	5 3	·063	175 1 2	1 15 7	·427	30 12 5	6 2	·074	569 9 6	5 15 8	1·388	2 10 9
Soho	247	176,111,858	478 13 0	2 14 4	·652	58 8 9	6 7	·079	186 6 11	1 1 2	·254	115 17 11	13 1	·157	839 6 7	4 15 2	1·142	1 18 6
Hotham Street......	205	90,893,190	331 10 6	3 12 3	·867	31 5 10	6 10	·082	141 9 5	1 11 0	·372	47 8 6	10 4	·124	551 14 3	6 0 5	1·445	2 18 9
Water Street	257	156,426,075	407 6 9	2 12 0	·624	57 13 1	7 4	·088	190 1 10	1 4 4	·292	42 15 2	5 4	·064	697 16 10	4 9 0	1·068	1 14 8
Total or Average ...	...	2,419,930,268	4193 7 6	1 14 8	·416	594 9 1	4 11	·059	1948 4 10	0 16 1	·193	861 6 8	7 1	·085	7597 8 1	3 2 9	0·753	1 19 6

* The repairs at Green Lane during this particular year were heavier than usual.

TABLE III.

Liverpool Water Works.

Comparative Economic Value of different mixtures of Lancashire Coal and Slack.

Number of experiment.	Duration of experiment.	Fuel consumed.			Total Number of Strokes.	Load lifted per stroke.	Mean Height of Lift.	Weight lifted one foot high per cwt. of fuel.	Comparative Economic Value of Fuel.	Ashes.		Water evaporated.	
		Coal.	Slack.	Total.						Total weight.	Per cent. on fuel.	Total.	Per lb. of fuel.
No.	Hours.	Tons.	Tons.	Tons.	No.	Lbs.	Feet.	Lbs.		Lbs.	Per cent.	Gallons.	Lbs.
1	105	5·00	5·00	10·00	58,020	835	268·72	65,092,986	1·0000	1627	7·26	19,390	8·65
2	100	5·00	5·00	10·00	55,950	835	269·43	62,936,490	0·9668	1872	8·35	18,490	8·25
3	95	5·00	5·00	10·00	52,570	835	269·08	59,057,611	0·9072	1314	5·86	17,410	7·77
4	97	5·09	5·31	10·40	53,300	835	268·82	57,519,079	0·8836	2149	9·22	17,550	7·53
5	87	5·00	5·00	10·00	48,290	835	269·02	54,237,323	0·8332	1722	7·68	15,950	7·12
6	85	5·00	5·00	10·00	47,400	835	268·83	53,200,112	0·8173	1865	8·32	15,780	7·04
7	84	5·00	5·00	10·00	45,860	835	269·50	51,599,952	0·7927	1338	5·97	14,990	6·69
8	79	5·00	5·00	10·00	44,290	835	267·36	49,437,838	0·7595	857	3·82	14,640	6·53
9	80	5·10	5·05	10·15	44,770	835	267·23	49,211,062	0·7560	1910	8·40	14,780	6·50
10	79	5·00	5·00	10·00	43,620	835	269·42	49,065,019	0·7537	1675	7·47	14,510	6·48
11	81	5·15	5·17	10·32	44,420	835	269·20	48,352,622	0·7428	2006	8·67	14,890	6·44

The CHAIRMAN enquired in what way the gutta-percha beats were applied in the pump valves, and how long they were found to stand in work; also whether vulcanised india-rubber had been tried for the purpose.

Mr. DUNCAN replied that he had not tried vulcanised india-rubber for the valve beats. The gutta-percha beats were put in just the same as the ordinary gunmetal beats in double-beat valves, and they lasted about six months in constant work before requiring renewal.

Mr. J. RAMSBOTTOM thought the bored and turned joints that had been described in the paper appeared a very good method of jointing the pipes of the mains, and much more economical than the ordinary lead joints. He enquired whether it was necessary to warm the ends of the pipes for making the joints, and whether the asphalt when cold was in a condition to admit of being set up with a caulking chisel in the ordinary manner.

Mr. DUNCAN replied that it was necessary to warm the sockets of the pipes in making the joints, in order to cause a slight expansion, so that the subsequent contraction in cooling might make the joint completely tight; and a single thread of tarred yarn lapped round the spigot end was found quite enough to afford the very small amount of elasticity needed in the joints. The asphalt was then run in, and no upsetting was required afterwards, as it was sufficiently liquid to fill every part of the space between the spigot and socket. He had tested joints made in this way up to a pressure of 200 lbs. per square inch without any leakage taking place. The pipes at present laid with the bored and turned joints had however been of much smaller dimensions than the large water works mains described in the paper, and the mode of warming the sockets for making the joints was by means of a coke fire in a cradle, over which the socket end of the pipe was suspended horizontally and turned round slowly till sufficiently warmed. For large pipes however, such as the 44 inch main, he proposed to heat an iron ring in a furnace and then slip it inside the socket for a few minutes to warm the socket.

The CHAIRMAN thought there would be no practical difficulty in applying that mode of jointing to large pipes if they did not get out of shape in warming the sockets. He asked what was the

largest size of pipe that had yet been laid with the bored and turned joints.

Mr. Duncan replied that the largest pipes he had hitherto laid with the new joints were 11 inches diameter; some at Glasgow were being laid of 15 inches diameter, and some made for Melbourne were 30 inches diameter.

Mr. J. Cunningham enquired what was the inclination of the taper that was found to answer best in the bored and turned joints.

Mr. Duncan replied that the inclination was 1 in 62 to the axis of the pipe: a higher inclination had been tried but did not suit so well, as the joints then began to show leakage at the testing pressure.

Mr. W. King observed that the bored and turned joints had been used by his father for the gas pipes in Liverpool from 24 inches down to 3 inches diameter for the last thirty years, and they had proved thoroughly satisfactory. The inclination of the taper of the joints was 1 in 32 on each side, and experience had shown that for gas pipes this taper completely answered the purpose.

Mr. J. Kennan had heard that at the Dublin Water Works the joints of the pipes were made taper similarly to those now described, except that they were not bored and turned but put together rough. The mode of laying them was to lay two pipes with the tapered end of one in the socket of the other, and then a block of wood being placed across the outer end of the second pipe, a third pipe was swung against it endways, so as to drive the joint up tight between the two first pipes; afterwards the ordinary packing of tow was rammed in and the socket closed with lead.

Mr. C. Markham enquired whether the 24 inch pipes that had been deflected under pressure in the experiment described in the paper had the bored and turned joints put together without any lead.

Mr. Duncan replied that the joints experimented upon were made exactly in the manner he had described, without any lead, being merely bored and turned and put together with asphalt. The pipes at Dublin that had been referred to, with taper joints put together rough, were only overflow pipes for carrying off the surplus water from the reservoir, and the joints therefore were not required to be made good enough for standing a heavy pressure without leakage.

Mr. Duncan said he had constructed meters himself, which he had now had at work for five years, and though somewhat expensive they always indicated within one per cent. on either side of the actual quantity, when treated with moderate care. He had tried the single cylinder meters with tumbling lever for reversing the valve, and had found the constant knocking was apt to end in a breakage, and if the tumbler ever stopped on the centre it allowed the water to flow through the meter without being indicated. This he considered a radical defect in any construction of meter, and his object had therefore been to obtain one that was sufficiently simple in construction and could not be tampered with and would continue in efficient working order for a considerable number of years, registering correctly the quantity of water passing through, without being liable to any derangement. The meters he had constructed had a pair of measuring cylinders with pistons and rods and slide valves, the pair being coupled together by a shaft with cranks at right angles, so that it was impossible for either piston to stick on the centres; and the piston rods were connected to the crank pins by slotted crossheads, having slightly curved slots allowing one cylinder to follow the other in action, with a smooth continuous flow of the water through the meter. A worm on the crank shaft worked the registering dial by means of gearing in the ordinary manner.

Mr. P. P. Marshall remarked that in the water works of the North London district, in order to prevent waste of the water, the service pipes had originally been fitted with "preventors," consisting of a long vertical cast iron cylinder containing a weighted gutta-percha ball of 3 inches diameter, the cylinder being made slightly larger in diameter, with the supply pipe entering at the bottom and the discharge pipe passing off from the top. When the tap was turned to draw off water, the rush of the water into the cylinder carried the ball with it and closed the orifice of the discharge pipe, so that only one cylinder full of water could be drawn off at a time; and when the tap was closed, the ball sank again gradually by its own weight to the bottom of the cylinder. These preventors however had now all been removed, as they were found inconvenient in use and did not affect the waste of water sensibly: for the great cause of waste was in the constant supply

system, when taps were liable to be left partly open, and here the preventor did not act, as a slight flow of water was not sufficient to raise the ball effectually, and then the water could run to waste. The parliamentary average for water supply was reckoned at from 5 to 25 gallons per day to each inhabitant, but in the North London district he was supplying from 60 to 70 and even 100 gallons per head per day. The best plan for preventing waste he thought would be to compel each house to have a cistern for the water, and to fill the cistern only once a day.

Mr. I. Smith hoped the use of cisterns would not be reverted to, for the report of the sanitary commission showed that where houses were supplied by cisterns a great deal more illness prevailed, especially among the poor, who would not keep the cisterns clean and covered over, and a quantity of foul matter gradually accumulated in them in consequence. Moreover cisterns were not really productive of much saving of waste he thought; for he had observed that in Walworth, London, when the supply of water was turned on, the practice was to take out the plug of the cistern and allow the water to run to waste until near the time of the supply being stopped, in order to cleanse the cistern with little trouble.

Mr. P. P. Marshall observed that outside cisterns might be arranged to be cleaned regularly by the local authorities supplying the water, without any trouble to the consumers; but in the case of internal cisterns that were covered over, he had found the necessity for cleaning scarcely ever arose where the water was pure. In reference to the poorer classes and small properties, the neglect was generally on the landlord's part, and he had known of some cases of houses being altogether deprived of water for many weeks through the landlord's neglect.

Mr. J. Mc F. Gray suggested that ordinary water taps might be made with a spring added, so as to keep them always shut, in order to prevent waste; and he had seen taps made with a sliding piston or plug, closed by a spring, which only ran so long as the plug was kept pressed down by the finger.

Mr. I. Smith said the objection to that sort of valve was that with a high pressure of water the sudden closing of the valve caused

too great a shock and damaged the pipes, by suddenly stopping the current of water. The india-rubber diaphragm valves closed by a screw were much superior in this respect, the diaphragm being made of cloth between two layers of india-rubber, so as to stand the screwing pressure; and the only objection he had found to them was that in careless hands they were apt to be screwed down too tight in shutting off the water, so that the india-rubber diaphragm was cut through, and had to be replaced.

Mr. J. J. Birckel enquired whether the sand washing apparatus at the filtering works continued to work efficiently, and what was the quantity of sand it would wash in regular work. He understood the original machine at Crewe, on the principle of which the present one was constructed, had proved very satisfactory in working.

Mr. Duncan replied that the sand washing machine had been found thoroughly satisfactory, washing 10 cubic yards of sand per hour and loading it into wagons ready for use.

The Chairman remarked that the Liverpool Water Works were amongst the finest at present in existence; and in consequence of their twofold character, partly gravitation and partly pumping, there was ample scope for future extension to meet the increasing requirements of so large a commercial town. He moved a vote of thanks to Mr. Duncan for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon the Members were conveyed by special steamer, granted for the occasion by the Cunard Steam Ship Co. through the kindness of Mr. MacIver, to the Mersey Steel and Iron Works, which were opened to their inspection: they were also handsomely entertained at the works by Mr. Clay. In returning, the steamer was taken round the Great Eastern steam ship lying in the river.

The Adjourned Meeting of the Members was held in the Concert Room, St. George's Hall, Liverpool, on Wednesday, 5th August, 1863; William Clay, Esq., Chairman of the Local Committee, in the Chair.

The following paper, communicated through Mr. George Harrison, was read :—

ON THE MECHANICAL VENTILATION AND WARMING OF ST. GEORGE'S HALL, LIVERPOOL.

By Mr. William Mackenzie, of Liverpool.

The works for Ventilating and Warming St. George's Hall, Liverpool, are from the plans of the late Dr. D. B. Reid, and may be classed under the five following heads:—Supply of Air, Warming, Cooling, Moisture, and Ventilation. The arrangements for these several purposes are shown in the diagrams, Plates 54, 55, and 56. Fig. 1, Plate 54, is a longitudinal section from end to end through the centre of the building. Figs. 2 and 3, Plate 55, are plans showing the arrangement of the air passages in the basement of the building, at the levels of the upper and the lower air channels respectively. Fig. 4, Plate 56, is a transverse section through the civil court, looking south. In all these diagrams the course of the air is indicated by the arrows, and the vitiated air is shown by the dotted portion.

Supply of Air.—The principal supply of air is by the two descending shafts A A, Figs. 3 and 4, Plates 55 and 56, at each end of the east portico. These are connected together by a long passage, from which there are lateral arches leading to the four ventilating fans B B that send the air through the building. On account of the graveyard on the west side of the building, air is not admitted on that side, except by windows and when the barometer is high. There are also supply shafts to each court, and openings along the sides of the central hall immediately above the windows, Fig. 1, Plate 54, by which air is brought down to the galleries of the hall, so that when necessary a very large additional supply of air can be obtained from the highest part of the building; but in general the supply from the shafts A A alone is preferred, and with few exceptions has been found sufficient.

Warming.—The air is warmed by means of two steam boilers C D, Fig. 3, Plate 55, and two hot water boilers E F; to which are

attached 32 coils of pipes, 5 for hot water, shown at G H I J K, and 27 for steam, of which 3 are shown at L M N. The pipes forming the hot water coils are 4 inches diameter, and those forming the steam coils 2 inches diameter; the supply pipe from the hot water boilers is 12 inches diameter, and that from the steam boilers is the same as the coils, 2 inches diameter. On the top of the hot water boilers expansion boxes are placed to receive the increased bulk of the heated water; and on the leading and other pipes there are expansion joints and stop valves, so as to keep the joints of the pipes in proper order. Thermometers are placed in front of the hot water boilers E F, as well as on the main coils H I, so that the difference in temperature between the flow and return pipes is easily ascertained. The average heat in the hot water boilers is 150° Fahr., the return water being from 15° to 20° cooler. In connexion with the coils there is an arrangement of air valves in the chambers, which effectually shuts off the heat when a reduction of temperature is required, so as to avoid running off the hot water from the boilers. The water in the boilers and pipes is changed as seldom as possible, so as to prevent corrosion in them. The hot water apparatus is the important source of heat for the principal parts of the building, and is the one always used, except in extreme cold weather; since the less the temperature is elevated, the more agreeable is the quality of the air.

The five hot water coils are arranged in the situations shown in the plan, Fig. 3, Plate 55, and are as follow:—

1. The main south coil H
2. The main north coil I
3. The south hall coil G
4. The west concert coil J
5. The east concert coil K

The heat from the whole of the coils can be directed on any given apartment or subdivided as occasion requires by opening or closing the numerous valves or doors in the air chambers that extend over the whole building, in a manner very similar to the mode of regulating the ventilation in a coal mine. In simply warming the building, all the valves for the escape of vitiated air are closed, and the same air is driven by the fans round and round the hall, courts, and corridors, until the required temperature has been reached. By thus preventing

the escape of warm air before it is contaminated, a considerable saving is effected in the consumption of fuel. The building is kept at a temperature as near 65° as possible. The fuel used for the boilers is soft coke, but ordinary gas coke is used for the open fireplaces, the great height of the smoke shafts causing a very powerful draught.

The steam apparatus, of which three coils are shown at L M N, Fig. 3, Plate 55, is used principally as an auxiliary warming power, and in the winter months the steam coils are used in the early part of the morning before the commencement of business, to warm the halls and passages; and the heat is afterwards maintained by the hot water coils, depending of course upon the state of the external atmosphere, the quantity of air required, and the manner in which the water apparatus may at the time be in use. All the coils have their appropriate stop valves, and can be put in operation either collectively or individually. In very cold weather, or when heat is suddenly or quickly required, then by an arrangement of steam pipes the steam itself is blown into the warm air passages, care being taken that no more is given than the atmosphere will absorb.

Cooling.—In the summer the various hot water coils are used for cooling the air, cold water being introduced into them instead of hot, and caused to run through them to such an extent as may be necessary. The vaults however are always so cool that this process is seldom resorted to.

Moisture.—In artificial warming, moisture is of the greatest importance, for if the air is warmed to a summer heat it ought also to possess the summer moisture. A special steam boiler O, Fig. 3, Plate 55, is employed for this purpose, to which pipes are attached so as to convey the steam to each of the principal warming apparatus where moisture is most likely to be required; the steam is there discharged into the air, the quantity being regulated by a hygrometer. To prevent the steam from imparting any objectionable effluvium to the air, the boiler is made of copper and the pipes of block tin 2 inches diameter.

In addition to this steam boiler there is a fountain P in the entrance air shafts A A, Figs. 3 and 4, Plates 55 and 56, so that

before the air is allowed to enter the cold air chambers it must pass through a spray of water varying from a gentle shower to a saturating mist, not so much for the purpose of receiving moisture, but in order that it may be washed and thereby caused to enter the building free from smuts and dust. Were it not for this provision, the smell of soot from a neighbouring chimney on fire or any other offensive smell would at once be drawn into the fans and wafted throughout the building.

Ventilation.—The ventilating arrangements have been made so as to secure from 7 to 10 cubic feet of air per minute to each person occupying the building, and the extent of opening of the supply valves is therefore regulated by the number of persons present, the quantity of air driven through the building varying from 1,000 to 50,000 cubic feet per minute. The openings for the diffusion of the air into the several compartments of the building are as numerous as its structural arrangements will allow, and they are controlled in such a way that the whole or only a portion of them can be open at one time.

Exactly under the middle of the floor of the central hall a 10 horse steam engine is fixed at R, Figs. 1 and 3, Plates 54 and 55, for the purpose of driving the four fans B B, which are 10 feet diameter and 5 feet broad, the blades being 2½ feet in width; they are driven at a speed of from 45 to 60 revolutions per minute. The engine is horizontal, and the fans are placed one on each of its sides, and are known from their position as the north, south, east, and west fans. The space between the floor of the hall and the engine room is divided into three channels S, Fig. 4, Plate 56, called respectively the cold, warm, and temperate air channels. Each fan has its own section, and the four fans may thus be working simultaneously on different portions of the building, distributing air at various temperatures according to the occupation of the different apartments. When necessary however all the four fans can easily be concentrated and made to supply air to any one section of the building. Thus the air may be driven through the main north coil I, and after being warmed thereby may be conveyed to the civil court and the concert room, Fig. 1; whilst the main south hot water apparatus H may be shut off, so that cold air is supplied to the central hall and the crown court. These arrangements

can be readily interchanged in any manner desirable, by simply altering the arrangement of the valves in the air passages.

In an edifice like this, where the requirements are so varied, it is most important that ample mechanical power should be available so as to meet the sudden changes that frequently arise, as for instance when the building is wholly or partially occupied. Special care has therefore been taken to have sufficient power to meet every change of circumstance, such as a sudden increase or decrease of numbers occupying any of the large apartments, either case requiring a corresponding alteration to be made in the working of the ventilation, and at the same time to be effected without causing discomfort. At a concert in the large central hall, Fig. 1, Plate 54, it often happens that one part of the room may be crowded to excess, whereas in another part it may be nearly empty; and this is more particularly illustrated when seats are reserved for a portion of the audience in evening dress, and the other parts of the room are filled by persons in ordinary dress. It is obvious that the same temperature will not be agreeable to both, and consequently arrangements are made by which those in the reserved seats are kept in a temperature considerably warmer than would be pleasant to those in the body of the hall. In many cases more depends upon the rapidity of circulation of the air than upon its actual temperature, which may be the same for all parts of the hall, or if necessary varied. This also applies to the crown court and civil court, which are divided into zones, giving a separate supply to the judge, bar, and general public, one part of the court being much more crowded than another. The temperature of the principal apartments is recorded every hour, and for this purpose a number of thermometers are placed in different parts of the central hall, courts, and concert room. The rapidity of circulation causes a difference between the apparent and actual temperature, the latter being higher than is imagined by those exposed to it; and consequently the thermometers are locked up and concealed from ordinary observation, because under certain circumstances it is better to increase the velocity of the air at a high temperature and thus make it feel cooler, than to reduce the temperature by supplying cold air and thereby causing discomfort to those who happen to be near to the openings for supply.

A person may feel very warm whilst walking during a hot summer day; but in riding on a vehicle driven at an ordinary speed, the air without change of temperature becomes agreeably cool. By the aid therefore of the engine and fans, complete control is exercised over the quantity of air supplied, giving at the same time the effect of a plenum of pressure, which can alone entirely neutralise draughts and currents at doors in crowded apartments.

The vitiated air is discharged at the ceilings of all the apartments, as shown by the dotted portions in the diagrams, Figs. 1 and 4, Plates 54 and 56; and after passing through channels between the ceilings and roofs is discharged into the external atmosphere by the four shafts T, Fig. 4, forming the angles of the central hall. Every panel or opening in the ceilings is controlled by a valve, and the number that may at any time be open depends upon the quantity of fresh air supplied from below, the supply regulating the discharge. With the exception of the central hall, the whole of the vitiated air from the concert room, courts, rooms, and cells is drawn towards the four shafts T; and in order that this may be done as effectually as possible, provision is made for coke fires and large jets of gas to be used as occasion may require, for rarefying the air in these shafts and thereby drawing off the vitiated air more rapidly. The draught of the shafts is controlled by iron doors, and can be regulated to suit the various movements to which the ventilation of the building is adapted. Owing to the great height of the central hall, the four shafts T are not available for this portion of the building; and the vitiated air from it is therefore discharged through the ceiling of the hall into a large foul air chamber formed between the ceiling and roof, and afterwards into the open air through glass louvres U, Fig. 1, which extend all around the highest part of the roof. These louvres are controlled by valves, so that any side may be used for the discharge of the vitiated air, according to the direction of the wind.

In order that the force or velocity of the air circulating through the building may be readily tested, with regard to either supply or discharge, small anemometers are placed at all the supply and discharge valves. These are simply paper cylinders, about 1 inch

long and ¾ inch diameter, suspended permanently in a vertical position by silk threads; and from the angle at which they are inclined by the current of air, the strength of the current is observed. By this means it is easy to perceive from the floor of the central hall whether the discharge valves in the ceiling are open or shut; and thus a check is always kept on the men whose duty it is to carry out the ventilation.

The various chimneys of the building are collected into the four shafts T, Fig. 4, Plate 56; but before reaching them the smoke from the individual fireplaces in the various rooms is collected into horizontal flues of large area, passing beneath the roofs, lower than the highest portions of the building, and afterwards ascending by the vertical shafts T. These four great shafts are each divided into three compartments, two being for the smoke and one for the vitiated air, each of the four large boilers C D E F, Fig. 3, Plate 55, having a special flue to itself. On the top of these shafts but not reaching above the height of the parapet wall, iron louvres are fixed, made of angle iron and thin sheet iron, and constructed so as to allow the vitiated air and smoke to escape as well as to prevent the rain from descending. Surrounding these louvres deflectors are placed for the purpose of breaking the force of the wind, thereby causing an eddy, and thus preventing a down draught. Dr. Reid considered that in introducing these shafts he had effected a great saving in the architectural expense, besides maintaining more strictly the style of architecture adopted. These four shafts have prevented the introduction of ornamental chimneys, and have saved the building from the unsightly incongruities too frequently seen on the chimney tops of public buildings for the purpose of preventing a down draught.

The air valves in the warm air chambers are light wood frames, covered with canvas and strong paper, and afterwards painted so as to allow of washing. The walls of the warm air chambers, instead of being plastered in the usual manner, are covered with cinders and plaster from 2 to 3 inches in thickness, so as to enable them to retain the heat when once they are warmed; and by this means a considerable saving is effected in the production of heat on subsequent occasions. The position of the boilers C D E F, Fig. 3, Plate 55, underneath the floor of the central hall, Fig. 1, might

probably cause some fear as regards explosion; but the working pressure is so far below what the boilers can sustain, and so regulated by gauges in connexion with the manager's office by means of magnetic wires to an alarum, as well as by steam gauges fixed on the office wall, that the fixed limit of pressure cannot be exceeded without immediate discovery.

In conclusion it may be stated that the building is an immense pneumatic machine, kept in operation according to the necessities of its occupation. When the building is unoccupied, the air courses through the warm and cold air chambers, the halls, courts, and corridors, to the extremities of the building; whence it returns to its central source to be again dispersed. But with the building in occupation, the order is different: the air then becomes contaminated and is discharged, and the supply and discharge are proportioned to the extent of contamination. It is easy to admit air or remove it from any part of the building, or to reduce the action: but the amount of satisfaction finally depends on the skill and delicacy with which the movement, temperature, moisture, and quantity of the air are adjusted, so as to suit the feelings of the audiences during the various seasons of the year. To do this effectually, care has to be taken as far as possible to anticipate every change that fluctuating circumstances may render desirable; but at the same time not to yield too easily to the mere importunities of any persons of delicate constitutions, who are usually the first to demand and the last who should guide any change that may be in opposition to the general feelings of those who are present.

The CHAIRMAN enquired what was the limit of pressure of the steam in the boilers employed for driving the engine and for warming, and what construction of boilers was used.

Mr. MACKENZIE replied that the boilers were all ordinary Cornish boilers, cylindrical with a single flue through them. The steam pressure was limited to 30 lbs. per square inch above the atmosphere;

and by the system of safety apparatus that was adopted as described in the paper, and the electric indicator communicating with his own office, a complete check was provided against any risk of this pressure being exceeded in work.

Mr. F. J. Bramwell observed that he had had an opportunity of inspecting the arrangements described in the paper for the ventilation and warming of St. George's Hall, which appeared to him to be very perfectly effected. With reference to the mode of cooling the air in hot weather by filling the ordinary hot water apparatus with cold water, he enquired how the water was obtained cold enough for that purpose, as the water might be expected to be near the same temperature as the external atmosphere, in which condition it would not be of use for cooling the air. He asked also what proportion of moisture in the air had been found by experience to be most desirable at the different temperatures, and whether the dry and wet bulb thermometer was used for ascertaining the degree of humidity; it was a delicate matter in ventilation to adjust the moisture in the air to the point at which the air could be breathed with comfort. He fully concurred in the necessity of washing the air to cleanse it from impurities, having had opportunities of observing the great amount of impurities with which the air was charged in large towns. In the case of a large corn mill in London running 32 pairs of stones, where he had put up four fans of 3 feet diameter for supplying the stones with air to facilitate the process of grinding the grain, the fine flour dust which remained suspended in the air and was collected for use had been found to be so blackened by the impurities mixed with it by the air as to be unfit for any except the commonest purposes, such as making paste for bill posting and other analogous purposes. As the air driven through the stones was required to be as dry as possible, in order to assist in taking moisture from the flour, the air could not be cleansed in this instance by washing: and he had therefore put up a number of fine dry canvas screens, one behind another, for the air to be strained through on its way to the fans, and it was astonishing to find the quantity of dirt that accumulated on these screens in a short time, showing the great extent to which the air of London was contaminated with impurities.

Mr. Mackenzie said the temperature of the water used for cooling the air in hot weather was generally about 54° or 55° Fahr. as supplied direct from the water works mains, when the air itself was at about 60° or even higher, so that there was sufficient difference of temperature to allow of the air being considerably cooled by the circulation of the water through the pipes. For ascertaining the degree of moisture in the air, wet and dry bulb thermometers were constantly employed in the air passages, and by adjusting the moistening apparatus a difference of 4° was regularly maintained between the two bulbs, which was found to give just the proportion of moisture that was pleasant for breathing. In reference to cleansing the air by washing it previous to its dispersion into the building, the effect of the cleansing had been found to be a saving of about 24 shillings a week in the cost of cleaning the air passages, valves, and pipes, two persons being now dispensed with that were previously required for that purpose.

Mr. F. J. Bramwell remarked that Liverpool was fortunate in having a supply of water from the water works at as low a temperature as 54° in hot weather: in London it was rare to find the water from the mains nearly so cool as that during the summer. In the two steam boilers that were used for heating the numerous steam coils he enquired whether the water was returned to the boilers after condensation, or whether fresh water was supplied to the boilers.

Mr. Mackenzie replied that the water from the steam coils was not returned to the boilers, but fresh water was put in. It was only in the hot water pipes and the two hot water boilers that the same water was used over and over again, because in that case the temperature of the water was always below the boiling point, amounting to only about 150°, so that no steam was generated and none of the water evaporated; but these boilers also were discharged at regular intervals and refilled with a fresh supply, while the pipes themselves were not emptied except on rare occasions.

Mr. T. W. Plum thought the plan of admitting the fresh air at the bottom of the apartments to be ventilated and taking off the foul air at the top was contrary to the principles of natural ventilation;

and suggested that the better way would be to admit the fresh air at the top and remove the vitiated air below, especially in churches and other large public buildings. By this means a constant supply of fresh air would be imperceptibly provided for breathing, instead of being first partly contaminated by entering at the feet and passing up over the surface of the body.

Mr. Mackenzie observed that the objection to admitting the fresh air above and drawing off the foul air below was that by that plan the descending fresh air would draw down with it the products of combustion from the gas chandeliers, which in the present system were carried off with the products of respiration at the top of the room. In the concert room in which they were now meeting, the fresh air was admitted at each of the risers of the steps running all round the wall of the room at the bottom, Fig. 1, Plate 54; and also through the panels round the wall of the gallery, each panel being perforated and controlled by a valve: and the foul air from respiration together with the products of combustion from the chandeliers was all taken off through the perforated panels in the ceiling. In the central hall there were three modes of admitting the fresh air,—1st at the level of the floor, 2nd through panels in the walls a few feet above the floor, and 3rd through openings in the galleries and above the large windows; all of these could be employed at once if necessary, whereby an abundant supply of fresh air was provided, even when the hall was fully occupied: and the foul air all passed off through the apertures in the ceiling.

Mr. W. E. Newton concurred in thinking the better plan for ventilation was to bring the fresh air down from above, but in that arrangement the system of lighting would have to be altered, so as to keep the heat and fumes of the gas burners separated from the fresh air entering the room; and there were several plans of lighting by which that might be readily accomplished. The first object he considered was to find out by experiment the best mode of ventilation, without regard to its expense; and when that was ascertained, no doubt means would be discovered of reducing the expense to a minimum. Under the system of ventilation described in the paper as carried out in St. George's Hall, the consequence of bringing in the

fresh air at the bottom of the rooms was that it became contaminated immediately on its entrance, through being breathed by the persons on the floor; and the whole room was therefore completely full of vitiated air. But if the air were admitted above and taken off below, and the lighting arrangements kept separate, it would not become contaminated until reaching the bottom, and the whole room would be full of pure air excepting only a thin stratum of vitiated air just at the floor level.

Mr. J. Fernie thought it was not the correct plan to admit the fresh air from above in large buildings, because the great difficulty in all such cases was to prevent down draughts. With the ordinary system of lighting from above, the gas burners near the ceiling necessarily produced a powerful ascending current, which was all available as an aid for ventilation when the fresh air was admitted below; but the whole advantage of this upward draught would be lost if the air were brought in at the top. He therefore thought Dr. Reid's mode of ventilation as here carried out was the correct plan.

Mr. I. Smith understood that the plan of admitting fresh warm air at the top and taking it away at the bottom by mechanical means, which was known as Van Hecke's method of ventilation, had been carried out at Baron Rothschild's new house in London; and the result was that so long as the rooms were not much occupied the ventilation was not bad, the vitiated air being then so greatly diluted by the large quantity of fresh air admitted; but when they were crowded and the gas lighted the air was not so good, owing to the hot impure air from the lungs and the highly heated products of combustion from the gas lights first rising to the upper part of the room. This effect might indeed have been anticipated, when it was remembered that in all ordinary buildings the air exhaled in breathing was at a considerably higher temperature than the atmosphere, being given off from the lungs at about 100° Fahr.; so that it would naturally rise, and could not be made to pass away with sufficient rapidity when taken off at the bottom of the building alone, while at the same time the fresh air descending from above became partly contaminated before it was used, by mixing with the rising vitiated air. In order to remedy the defect, a small portion of the impure air was taken off from the top of the room, and the remainder from the bottom.

Under particular circumstances no doubt it was right to admit the fresh air at the top, as in the case of Turkish baths, because there the temperature of the room was maintained at 120° to 140°, or 20° to 40° above that of the body, so that the air became in that case cooled instead of heated by respiration, and would therefore naturally pass off from the bottom of the room. But for ordinary public buildings he thought the system of ventilation carried out in St. George's Hall was the most perfect he had ever seen, the whole of the products of respiration and combustion being removed above and thereby prevented from tainting the pure air admitted below. The plan of forcing in the fresh air by mechanical means, by the four ventilating fans, had an important bearing on the success of the system, ensuring a constant plenum of pressure throughout the building, slightly in excess of the atmospheric pressure; in consequence of which it was impossible for any inward draught of cold air to take place when any of the doors were opened. Without resorting to such mechanical methods it appeared impracticable to ventilate large buildings satisfactorily; and he might mention that in the case of the Birmingham Town Hall the ventilation had hitherto been a complete failure, the only ventilating power being three large sunlights near the ceiling, which produced a strong upward current from the hall, but entailed also violent draughts through the doors whenever they were opened, and down draughts of cold air from the cooling surface of the windows when all the doors were closed: whereas if a supply of warm air were always brought in at the bottom the liability to down draughts would be obviated.

For the ventilation of dwelling houses or moderate sized workshops he had found mechanical appliances were not required; but the ventilation was efficiently accomplished by means of the simple ventilators on Mr. Muir's plan, which he had found invariably proved completely satisfactory, consisting of a vertical shaft or flue terminating at the top with open louvre sides and divided into four parts by two vertical partitions placed at right angles to each other: by this arrangement, in whatever direction the outer air might be moving or however slowly, the fresh air was made to pass down through two of the divisions into the apartment to be ventilated, while the vitiated air

ascended through the other two divisions of the shaft. For house ventilation the air was thus brought down from the roof, which was a point of great importance in towns, where the air was more impure at the level of the ground. The size of the chimney flues also required considerable alteration from the present practice, as he had found that the ordinary chimneys were built far too large in proportion to the rooms and the fires burnt, causing an incessant draught from the doors or windows; and for houses of two stories high flues 9 inches square or even smaller were amply sufficient for the lower rooms. A throttle valve or damper should be inserted in the flue above the fire, as recommended by Dr. Arnott, for regulating the amount of the draught according to the size of the fire or the rapidity with which it was wanted to burn: and the firegrates should be made entirely of firebrick, without any iron about them excepting the bars in front. He had himself carried out these plans at his own house, having had the chimneys bricked up to 9 inches square, with throttle valves inserted and firebrick grates; and the result had been that for the last five years, ever since the alteration had been made, he had never required the chimneys sweeping, as there was never any soot deposited in them.

The amount of impurities contained in the atmosphere in large towns was certainly astonishing; for on taking down a ventilator cap at the works he was connected with in Birmingham, after it had been up about five years, he had found the inside of the ventilator was coated with soot, and the inside trough 3 inches deep surrounding it was completely filled with soot and dust; whilst a ventilator which had been up the same length of time four miles out of the town was still free from any deposit of the kind. This showed that it was highly desirable for the air to be purified in large towns, by some process of washing such as had been described; and the purification was even more important for private houses than in ventilating public buildings.

Mr. J. Fernie enquired how long the system of ventilation in St. George's Hall had been in operation: and in what respect it differed from that of the House of Commons, where he understood Dr. Reid's plans had been adopted.

Mr. Mackenzie replied that the St. George's Hall was opened in 1854, and the system of ventilation now described had been constantly

at work with complete success from that time. This was the largest work that Dr. Reid had carried out, and the most successful, as in this building his own plans were thoroughly carried out, whereas at the House of Commons that was not the case: St. George's Hall was indeed the only large building where his system of ventilation had been carried out in its integrity according to his own views. The principle of the system was to assist the natural ventilation, instead of running counter to it; and the whole of the ventilating apparatus had proved entirely successful in working, without occasioning any difficulty at any time, and with no repairs or expenses beyond the ordinary working expenses of the engine and boilers.

The Chairman observed that the question of ventilation was one of great importance in all buildings, and more especially so in reference to public buildings in large towns. In the case of St. George's Hall he believed the ventilation was more efficiently accomplished than in any other large public building that he knew of, this being the only building in which Dr. Reid was supported by the architect and had his own plans thoroughly carried out. He moved a vote of thanks to Mr. Mackenzie for his paper, which was passed.

The following paper, communicated through Mr. John Ramsbottom, was then read :—

ON MACHINERY FOR THE MANUFACTURE OF PLATE GLASS.

By Mr. GEORGE H. DAGLISH, of St. Helen's.

Within the last ten years the production of Plate Glass in England has been quadrupled, whilst in the same time the price has been diminished fully one half. The present extent of the manufacture in this country is about 85,000 square feet per week, whilst about 12,000 square feet per week of foreign plate glass is imported. The foreign glass has obtained a preference from its superior lightness of colour, which arises from the greater purity of the materials that it is made of, particularly with regard to the sand, of which the foreign makers have an abundant supply, of great purity and light colour, as seen from the specimens now exhibited of English and foreign sand.

Under the influence of competition, the English manufacturers have lately commenced an extensive course of experiments with the view of improving the quality of the plate glass made in this country, and also reducing the cost of manufacture; and in some instances very decided success has thus far been the result. In order to accomplish these objects, the sand employed at the British Plate Glass Works at Ravenhead near St. Helen's is now imported from France; and every precaution is adopted to ensure as far as possible the chemical purity of the other ingredients of the glass. At these works also two of Mr. Siemens' regenerative gas furnaces (see Proceedings Inst. M. E., 1862, page 21) have been erected for melting the materials for the plate glass; and from the absence of smoke and dust in them, and the facilities they afford for regulating the heat, these furnaces have contributed greatly to the desired results. Under these altered circumstances the glass now manufactured is fully equal in every respect to the best samples of the French production.

As time is money, any improvement which tends to expedite the manufacture of glass is of importance. This is strongly exemplified in the process of annealing. After the materials have undergone the process of melting in the furnace and are considered in a fit state for casting, the pot containing the melted mass is taken to the casting table, and its contents poured out on one end of the table, in front of a large cast iron roller; the material is then spread out over the surface of the table by passing the roller over it, the thickness of the plate of glass being regulated by strips of iron placed along each side of the table, on which the ends of the roller run. As soon as the plate of glass is sufficiently solidified to bear removal, it is introduced into an annealing oven, there to be gradually reduced in temperature or "annealed," until it is fit to be exposed to the atmosphere without risk of fracture. This process of annealing used formerly to occupy upwards of a fortnight, but from the improved arrangement and construction of the annealing oven it is now completed in four days; thus three times the quantity of glass can now be annealed in each oven compared with what was formerly considered possible; and consequently a large outlay in building and in space has been saved, since only one layer of plates can be placed in the oven at one time, no method of piling the plates being considered practicable or even safe. The chemical difficulties and manipulation in producing the raw material have thus been very satisfactorily overcome; but the problem of carrying out the necessary improvements in the subsequent mechanical operations has not perhaps been so completely solved, though considerable strides have been made in that direction also.

The plates of glass when taken from the annealing ovens are exceedingly irregular, particularly on the surface which has been uppermost in the process of casting, that surface being undulated or wavy after the passage of the roller over it whilst in a semifluid state; the lower side too is affected by any irregularities on the surface of the casting table, and also to some extent by the floor of the annealing oven; and both sides of the plates are also covered with a hard skin, semi-opaque. The plates vary in size, the largest being about 17 feet long by 9½ feet wide; and the thickness varies

according to the size from 3-8ths to 5-8ths inch. The first process to which the plates are submitted is that of grinding, to take off the hard skin and reduce the surface to a uniform plane, which is performed by the application of sand and water. The second process is that of smoothing, which is a continuation of the first process, but performed with emery of seven different degrees of fineness, so as to prepare the surface of the glass for the final process of polishing. This last process is effected by the use of oxide of iron employed in a moist state.

The machine in general use for Grinding is that which was originally employed at the commencement of the glass manufacture, and is believed to have been designed by James Watt. It is known by the name of the "fly frame" machine, and is shown in side elevation and plan in Figs. 1 and 2, Plates 57 and 58. It consists of two benches of stone A A, sufficiently large to hold a plate of glass, and placed about 12 feet apart; on these benches the plates of glass are fixed by plaster of paris, as shown by the black line in Fig. 1. Each bench has a runner frame B made of wood, about 8 feet long by $4\frac{1}{2}$ feet wide, shod on the underside with plates of iron about 4 inches broad and $\frac{1}{4}$ inch thick, and provided with a strong wrought iron stud on the upper side, by which it is moved about over the surface of the glass. The gearing for driving these two runner frames B is placed between the two benches, and consists of the square cast iron fly frame C, with two flat bars D hinged to it on opposite sides, extending over each bench A, and suspended from the roof by long chains, as shown by the dotted lines in Fig. 1, so as to allow them to radiate freely in every direction; this is called the "fly frame" from the peculiar motion given to it, and each of the runner frames is connected to it by the central stud B, Fig. 1, working loosely in the slot between the bars D. The fly frame receives its motion from an upright spindle E, which is driven from the main line of shafting by a pair of bevil wheels with a friction clutch for throwing in and out of gear. On the top of the spindle E is a wrought iron arm or crank carrying a moveable stud, which works in a bush in the centre of the fly frame C. Round the centre

spindle E are also four other spindles F, equidistant from the centre spindle and from one another, each carrying on the top a wrought iron arm or crank with moveable stud similar to the centre one; these studs severally work in bushes at each corner of the fly frame. Hence when motion is given to the centre spindle E, the fly frame C is carried round by the stud on the crank arm, while its sides are always kept parallel to their original position by the four corner cranks F. The two runner frames B, being connected by their central stud to the arms D of the fly frame, receive the same circular motion as the fly frame; but at the same time they are left free to revolve round their own centres, which they do in a greater or less degree according to the varying friction of the grinding surfaces. The grinding motion being thus obtained, sand and water are constantly applied, until the surface of the glass is found upon examination to be free from all defects; the sand is then washed off the glass, and the first stage of the smoothing process is commenced on the same machine by substituting the coarser qualities of emery in place of the sand. The plate of glass is then removed from the bench, turned over and replaced on the bench, and submitted to the same process on the other side. The speed at which the fly frame is driven is about 40 revolutions per minute. It will be seen that the runner frame B, Fig. 2, is not sufficiently large to act upon the entire surface of a large plate of glass at one time; it is therefore necessary to divide the operation and shift the position of the runner frame as the work requires it, by inserting the centre stud of the runner frame into a different portion of the slot between the fly-frame bars D.

Until the last few years the principal part of the operation of Smoothing was effected by manual labour, the operation being performed by rubbing two pieces of glass together and applying emery powder between them. Great care is requisite as the work approaches completion that no scratching shall take place; and it is on this account that hand labour is considered absolutely necessary for finishing the process, the slightest scratch being immediately felt by a practised hand, whilst a single stray particle of grit on a machine would spoil the whole surface before it was perceived.

About 1857 Mr. Crossley introduced a machine for smoothing the plates of glass, which so far succeeded that the nicety of the hand touch is only required for the final part of the operation. This smoothing machine, shown in plan in Fig. 3, Plate 58, is exceedingly simple and inexpensive, consisting of a long wooden bar C, connected at one end to a crank E on an upright spindle, and extending over the stone bench A on which the plate of glass is laid; two runner frames B of wood are attached to the bar C, and on the underside of each frame is fixed another plate of glass; these are then laid upon the glass on the bench. In this case the runner frames B are only allowed to partake of the motion given to them by the bar, and are not left free to revolve round their own centres as in the grinding operation previously described. The centre of the bar C between the two runner frames is kept in position by a radius rod G secured to a fixed bracket on one side of the bench, at right angles to the direction of the bar. The crank E being set in motion, the bar and runner frames receive a movement somewhat similar to the figure 8, which is very similar to the motion given in manual labour. One advantage of this machine is that two surfaces of glass are finished at one operation. The space between the two runner frames B is found very convenient for applying the emery and also ascertaining the progress of the work, without having to stop the machine.

The machinery used in the Polishing process remains the same in principle as that originally constructed for the purpose. Each machine consists of a strong cast iron frame H, Figs. 4 and 5, Plate 59, about 18 feet long by 10 feet wide, containing a series of small rollers, upon which is placed a wooden table I with two racks on the underside; suitable gearing is connected to these racks, to give the table a slow alternate lateral motion so as to bring every part of the plate of glass under the action of the rubbers B. The plates of glass are fixed upon the table I by plaster of paris, and the ends of the table move between slide blocks secured to the main frame H, so as to prevent the action of the rubbers from displacing it. The rubber blocks B are pieces of wood covered with felt, and provided with a central spindle and adjustable weights to regulate

the amount of friction; a number of these blocks are secured to two moveable bars D, running on rollers J J at each end of the table I, and driven by a short shaft E with cranks at the ends set at right angles to each other. The rubber blocks are thus worked transversely to the motion of the table; and by applying the polishing powder in a liquid state the surface of the glass is gradually brought up to the requisite degree of polish, both sides of the plate successively being subjected to the same operation.

About 1857 experiments were commenced at the British Plate Glass Works at Ravenhead with an entirely different class of machinery for Grinding and Smoothing plate glass, with the object of increasing the production, reducing the cost, and also completing the process of smoothing upon the same machine on which the glass is ground, so as to obviate the necessity of a separate machine for smoothing, and also save the expense and loss of time in removing and refixing the plates of glass. The new grinding and smoothing machine is shown in Figs. 6 and 7, Plate 60, and consists of a revolving table K, 20 feet diameter, fixed upon a strong cast iron spindle L, and running at an average speed of 25 revolutions per minute, driven through an intermediate upright shaft M from the main line of shafting N by a pair of bevil wheels, and friction cone O for throwing in and out of gear. This arrangement of gearing for driving the table was made by Mr. Daglish, and was adopted in order to obtain a long spindle L for the table, of a length equal to the semi-diameter of the table, and at the same time to keep the main line of shafting N continuous, for driving a series of tables in one room. Over the top of the table a strong timber bar P is fixed, about 10 inches from its surface; and on the two opposite sides of this bar are bolted two notched plates of cast iron Q, one on each side of the centre of the table. The notches are for receiving the centre studs of the runner frames B, which are very similar to those used on the old class of machinery; and the runners can thus readily be moved nearer to or further from the centre of the table, as circumstances require, by shifting the stud into a different notch. The only

motion which these runner frames have is round their own centres, and this is given to them by the excess of friction on the side furthest from the centre of the table over that on the side nearest to the centre, this excess being caused by the greater velocity of the portion of the table further from the centre. It is evident that the amount of grinding action is considerably greater on this machine than upon the old one, both from the increased velocity of the runner frames themselves, and also from the double amount of movement obtained by the revolution of the table K and the runner frames B. The idea of driving the runner frames themselves, as well as the table, was conceived at an early stage of the experiments; but on being put to the test, it was found that the unaided movement of the runner frames adapted itself to the work to be performed far better than any compulsory motion could do. It has also the advantage of leaving the surface of the table free and unencumbered with any machinery, and consequently facilitates the operation of laying and removing the plates of glass: the whole of the driving machinery is also covered over and thus protected from the injurious effects of the sand and water thrown off from the edge of the table in working.

This machine has been found to answer equally well for smoothing as for grinding; and this is perhaps its most successful feature in a commercial and economical point of view. Both these processes are now completed on it at the Ravenhead Glass Works, the finishing portion of the smoothing operation alone being effected by manual labour for the reasons before stated. The plates of glass being generally oblong in form, it was found that the machine in its original shape, having a circular table K for carrying the glass, as shown by the dotted circle in Fig. 7, Plate 60, entailed considerable waste in filling up the area of each table for grinding; and it was then determined to alter the shape to that of an unequal sided octagon, or square with the corners taken off, as shown in the plan, Fig. 7: no difficulty has been experienced in the process of grinding from this alteration in form, whilst the amount of waste in making up the tables has been considerably reduced, and greater facilities are obtained for grinding large plates. The amount of wear and

tear on this machine has been found to be very small in comparison with the old machines, owing to the small number of working parts, the large extent of bearing surface, the smoothness of the motion, and the complete balancing of the table. The quantity of glass finished upon one of these machines per week is from 1200 to 1500 square feet, which is about one third more than the old machines are capable of doing, due allowance being made for the difference of area in them.

The first point to which attention should be directed for working out further improvement is the method adopted in casting the plates of glass, and the machinery employed to carry out the process. It has been stated that the plates of glass in their rough state are very irregular, so much so that about 40 per cent. of the glass is ground away in the subsequent processes, which is a serious waste of material and entails a great expenditure of time and material in the process of grinding; it is therefore worthy of consideration, whether some improvement may not be carried out in this direction by obtaining the plates of glass smoother in the first instance. The grinding and smoothing operations are believed to be now improved upon the previous practice, though there is no doubt room for further practical suggestions and appliances. The polishing process has been tried to a limited extent on the revolving table last described, but without any practical advantage: the present system is no doubt theoretically correct, as the action of the rubbers is regular and uniform over the whole surface of the glass, thus keeping up a uniform temperature; but some motion producing a continuous movement of the rubbers, instead of the present alternate movement, would no doubt reduce the wear and tear and require less power, and would probably also be found capable of a higher velocity, resulting in an increase of production, provided the other requisite conditions of the process were complied with.

Mr. Windus exhibited specimens of the plate glass from the several stages of the manufacture, in the rough state after casting, and after each of the processes of grinding, smoothing, and polishing. He also showed specimens of plate glass made from English and from French sand, together with samples of the sand from which they were made, showing the lighter colour and greater purity of the French sand.

Mr. F. J. Bramwell observed that reference had been made in the paper to the highly satisfactory working of Mr. Siemens' regenerative gas furnace as applied for melting the materials to make the glass at the Ravenhead Works: he had, as engineer to the company, recommended the adoption of that furnace for the purpose, being convinced of the great advantages that would be found to attend its use, and the first furnace on that construction had now been in constant work for fifteen months, and a second and larger furnace had been erected in May last, which had also been in constant work since that time. These furnaces he believed left nothing to be desired as far as regarded the melting: but in other respects he thought the process of making plate glass was at present in a most unsatisfactory position, and some improvements seemed to be much wanted in the mechanical contrivances used in the manufacture, though he must admit it was more easy to make that assertion than to show how the improvements were to be effected. A serious objection to the present arrangements was the great amount of handling that the plates of glass had to undergo in the several processes, which was evidently an important point when it was considered that the large plates fetched a higher price per square foot than smaller ones, and therefore it was desirable to avoid the risk of having to cut up large plates into smaller sizes on account of fractures. Under the present methods however the risk of fracture was great, from the number of times the plates were handled: on leaving the annealing oven the plate was handled once in conveying it to the grinding machine and bedding it there, and afterwards a second time in turning it over for grinding the second side; and similarly it had to be twice handled for each of the subsequent processes of smoothing and polishing, making six

times of handling altogether before the plate of glass was finished on the machines, after which it had still to be twice handled in the final operation of hand cleaning. All these processes he considered ought to be effected without more than twice laying the plate, once for each side; or even without laying the plate at all, by working on both sides of it simultaneously: and in this respect therefore he thought there was a wide field open for improvements in the plate glass manufacture.

The revolving grinding table that had been described was a decided improvement upon the old fly-frame grinding machine, since in all mechanical operations it was better to get rid of a reciprocating action wherever practicable, and replace it by a continuous circular motion. The new construction of grinding table was preferable to the old grinding benches, on account of its protecting all the machinery below it, so that the working parts and bearings were not exposed to injury from the grit thrown off profusely from the grinding table. A further advantage was the large size of the table, 20 feet diameter, which afforded room for working on the whole surface of a large plate of glass at once.

A serious cause of loss at present in the manufacture was the very large proportion of the glass that had to be removed in the process of grinding in order to obtain a level surface of the glass. The undulations on the surface of the plates before grinding could not he considered be produced by the roller on the casting table, as had been suggested, because the roller was of great weight and was moved forwards steadily, running at each end on a smooth strip of iron laid along each side of the casting table, by which the thickness of the plate of glass was determined; the surface of the glass appeared level before the plate was put into the annealing oven. The undulations after annealing were not in parallel furrows across the plates, but were in the form of hills and hollows, altogether irregular in size and position. It therefore appeared that the glass in annealing must contract irregularly, causing this unevenness of the surface, particularly on the side which had lain uppermost in the annealing oven, in consequence of which so large a proportion of the glass had to be ground away as waste in order to

obtain a level surface. In the old annealing ovens the plates had to be left a long time till the oven had cooled down of itself; but the ovens were now built with air channels under the bed, through which a current of cold air passed, so that the heat was reduced as quickly as was practicable without injury to the glass, whereby a great saving of time was effected. No method however had yet been devised for laying the plates one on another in the annealing oven, and consequently a large area of surface was required in the ovens in order to lay them all separately, some of the ovens being as much as 50 feet long for the purpose of annealing six large plates of glass at a time: the ovens were well designed for uniformity of heat in all parts, notwithstanding their great size.

Mr. R. Pilkington thought the reason of the uneven surface produced on some of the glass plates in annealing was that the oven was made too hot for the first plates that were put into it, in order that it might be hot enough for the last ones; and consequently the earlier plates had not become sufficiently set with a uniform degree of hardness before going into the oven. The glass certainly went into the oven quite smooth, and the unevenness must therefore arise in the annealing. At the St. Helen's Plate Glass Works they made what was known as Hartley's plate, fluted plates of glass $\frac{1}{2}$ inch thick, and these were annealed by being piled on the edge in a vertical annealing oven, as they were strong enough to stand on the edge in consequence of their corrugated form. A plan had also been tried of laying the flat plates one upon another in the annealing oven, by means of a lowering table in the oven; but the objection to this plan was that if the plates were at all too hot they stuck together and could not be separated again without breaking.

Mr. J. Fernie enquired whether in rolling out the glass on the casting table the roller was passed over the glass at a uniform speed without any jerking action: he thought if the roller was stopped or moved slower at any places that would account for the uneven surface, because the continued heat of the annealing oven would allow time for the glass to expand again at those places, when it might assume the irregular surface that was noticed.

Mr. F. J. Bramwell replied that although the roller was moved over the glass by hand there was no jerking action or irregularity in the motion; and therefore he did not think the uneven surface could be accounted for in that way, but must be due entirely to the unequal effect of the heat upon different portions of the plates in the annealing oven. It was true that just before the plate was slid off the casting table into the oven, the glow of the newly rolled hot glass had the appearance of being in parallel stripes across the plate, although at that time the surface was really level; but after the annealing, the unevenness of surface did not show itself in parallel furrows, but in irregular hollows over all parts of the plate, as had been already mentioned.

Mr. W. Danson enquired where the foreign sand was obtained that was used for making plate glass, and whether sand from Sydney in New South Wales was ever used; this had been imported about thirty years ago for the purpose, but was not found to answer at that time.

Mr. Windus was not aware whether the sand from Sydney had been used for glass making: the foreign sand used for the purpose, of which a specimen was now exhibited, was from Fontainebleau near Paris.

Mr. R. Pilkington observed that the great cost of importing foreign sand for making plate glass was a heavy expense in the manufacture. The French sand cost about 21*s.* per ton, as compared with only 3*s.* per ton for English sand including cleansing by washing; but the latter when washed clean of impurities was good enough for the manufacture of sheet glass.

Mr. D. Adamson suggested that it would be desirable to ascertain the nature of the geological strata in which the fine Fontainebleau sand was found: for in England there were so many varieties of sand along the coasts, and so great a range of geological formation was developed throughout the country, that no doubt if the peculiar qualities of the French sand were fully investigated some of the English river or coast sands might be found to be equally suitable for plate glass manufacture.

Mr. J. Silvester enquired whether the use of iron plates laid upon the upper surface of the glass had been tried for flattening the glass in the annealing oven: these were used successfully for flattening sheet steel, which was rendered necessary by the tendency of the sheet to buckle in hardening, but if made perfectly flat during the process of tempering it remained so afterwards, and he thought the same plan might answer for flattening plates of glass.

Mr. F. J. Bramwell thought there would be a good deal of difficulty in employing iron plates as covers for keeping the plates of glass flat in the annealing oven, on account of the large size of plates that would be required, 180 inches long by 80 to 100 inches wide. The expense too would be large, since as many iron covers would be required as there were plates of glass, say half a dozen in each oven. Moreover the iron would have to stand heating up to a low cherry red heat every time of charging the annealing oven.

Mr. R. Pilkington did not think iron plates had been used either to maintain an even surface of the large sheets of cast plate glass or to form the bed upon which the glass was to be annealed. With regard to the sand used for making the glass, the main difference between the foreign and English sand was that the former was entirely free from iron, while the English sand was always found to be impregnated with it; and no cleaning process was successful in getting rid of the iron. The foreign sand from Fontainebleau was found on clay. In washing the sand for use the apparatus employed was similar to that which had been described as used for washing the sand for the filter beds of the Liverpool Water Works: but for the water works the finest sand was washed away, and only the coarser quality was retained for use in the filter beds; whereas for glass making it was the finest sand that was wanted, and the coarser portion was rejected.

Mr. F. J. Bramwell remarked that in grinding the emery that was used for smoothing and polishing the plates of glass it had formerly been customary to grind it dry under edge runners; but recently a valuable improvement had been made by grinding it in a stream of water, the whole apparatus being otherwise the same. The saving of time thus effected was so considerable that two days

a week were now sufficient to grind all the emery formerly ground in a week; while at the same time there was no waste of the emery from the fine dry powder flying about in the air, and the absence of this dust in the works caused a great improvement in the workmen's health. The reason of the saving of time in grinding the emery with a stream of water was the same as in the case of grinding corn with an air blast between the stones: directly any portion of the corn was ground so fine that it ought to leave the stones, the blast carried it away, so that the stones were always operating upon nothing but what they ought to grind; and in the same way the stream of water removed the fine emery powder as soon as ground, and left only the coarser particles under the stones, thus producing a most satisfactory result in economy of time.

The subsequent process of sorting or separating the several qualities of the ground emery according to the degree of fineness of the powder was also of great practical importance in plate glass manufacture. The method adopted was the same as that used for sorting or washing the ore at lead mines: the different sizes of particles were separated by the action of gravity, by means of a series of streams of water of diminishing velocity, through which the particles of emery sank according to their size. This was one of the most simple and beautiful contrivances that he was acquainted with, and proved completely successful in preventing any of the coarser particles from getting mixed with the finer sorts of emery powder.

Mr. W. E. Newton remarked that for separating substances having different sizes of particles there were two methods that might be employed, the wet and the dry. The former had already been described in the case of separating the particles of emery by streams of water running at different velocities; in the dry method the separation was effected by a blast of air. The latter plan was devised and employed by Mr. Bentall of Weybridge for separating into different degrees of fineness the coal dust which he used in his foundry for making castings, whereby he obtained castings much superior to those generally produced for agricultural purposes. The coal was crushed by edge runners to a great degree

of fineness, and an air blast from a fan blew the dust into a long covered box or chamber about 30 feet long, the bottom of which was divided into four lengths or compartments: the finest dust was carried to the extreme end of the chamber and deposited in the furthest compartment, while the coarser and heavier particles fell into the nearer compartments, according to their respective sizes, the coarsest falling nearest to the grinding apparatus. The process was found most satisfactory in producing a distinct and accurate separation of the different sorts of coal dust; and he had himself examined with a microscope the particles of dust deposited, and found them very uniform in size at any one part of the long chamber. In this process also the ground coal dust was removed immediately from the grinding apparatus by the air blast, instead of remaining there to clog the grinding. The same method would he thought be applicable for separating emery into its different degrees of fineness for polishing glass, if it were preferred to separate it dry instead of employing water for the purpose.

The CHAIRMAN thought it was matter of regret that no means had yet been arrived at for making the best plate glass from home sand, instead of foreign sand; and he suggested that some mechanical mode of bleaching the sand might be discovered, to render the English sand as good for the purpose as the foreign sand: the application of heat might perhaps be tried, as that was known to produce a great difference in the colour of many materials, such as clays and other earths.

With regard to the origin of the waviness on the surface of the glass plates after leaving the annealing oven, it had been stated that this unevenness did not exist when the roller left the surface of the glass on the casting table, but that it became developed during the gradual cooling of the plate in the annealing oven; and it occurred to him that possibly the glass at the time of casting might be in a viscid or plastic state, like gutta-percha, instead of being completely and uniformly liquified throughout the entire mass, the result of which would be that it would yield under the roller, but the rolled plate would be irregular in density and would thus become uneven during annealing by swelling up again at various parts. If however the

unevenness could be prevented by packing the plates of glass between iron plates in the annealing oven, as had been suggested, he thought the saving effected by the smoother surface in the subsequent grinding process might make up for the additional expense of the iron plates in the first instance; and the number of iron plates required would be only one more than the number of glass plates to be laid between them, if they were laid in a continuous pile.

The particulars given in the paper regarding the increase in the manufacture of plate glass during the last few years afforded another and a very clear illustration of the effect of cheapening any article in causing a great extension of its use. He moved a vote of thanks to Mr. Daglish for his paper, and also to Mr. Windus, which was passed.

The following paper was then read:—

DESCRIPTION OF THE NEW IRON WORKS AT GROSMONT.

By Mr. HIRAM C. COULTHARD, of Blackburn.

In the Cleveland iron district, where the Grosmont Iron Works forming the subject of this paper are situated, there are at present 63 blast furnaces in full operation, 17 furnaces not in operation, standing for repairs or other causes, and 11 furnaces in various stages of progress. The Grosmont furnaces have been erected by Messrs. Bagnall, and the general working arrangements for them were made by the manager, Mr. Barnes, and the writer of the present paper; and upon the latter devolved the arrangement of engines and boilers, &c.

Grosmont near the coast of Yorkshire is situated about 7 miles from the port of Whitby, 20 miles from the Durham coalfield, and about the same distance from the lime district of Pickering, whence the supply of lime is derived. Fig. 1, Plate 61, is a general plan of the entire works, which are adjacent to the main line of railway from Whitby to Castleton, joining the North Yorkshire and Cleveland Railway, and thus in connexion with the Newcastle and Durham coal and coke districts. A siding from the main line runs into the works.

These blast furnaces are believed to be constructed on a very efficient and economical plan for the purposes intended. Each furnace is capable of producing 250 tons of pig iron per week, allowing for stoppages on Sunday. Fig. 2, Plate 62, is a vertical section of one furnace, and Fig. 3, Plate 63, shows an enlarged vertical section of the top and bottom of the furnace. Figs. 4 to 8, Plate 64, are transverse sections of the furnace at the tuyeres, tapping hole, and hearth, and through the body of the furnace.

Each furnace measures 18 feet diameter at the boshes, and a total height of 63 feet from ground line to level of charging floor. The foundations were dug out to a depth of about 9 feet, to rock on one side and hard blue clay on the other, the ground sloping in the direction of the dip of the rock. The stone foundations both for the hearth and casing of the furnace are shown in the vertical sections, Figs. 2 and 3, Plates 62 and 63, and consist of ring courses of masonry built on concrete, about 26 feet diameter, each course being bound by a wrought iron ring, 5 inches wide and $\frac{7}{8}$ inch thick, Fig. 3. In the interior of the uppermost ring course is built the firebrick hearth A, Fig. 3; the blocks of which this is formed are shown in plan and vertical section in Figs. 6 and 7, Plate 64. These blocks are set in ground fireclay in a moist state, special care being taken to secure a perfectly homogeneous mass, as the whole of the superstructure of the furnace and its contents when in working order, weighing about 1200 tons, rest upon this foundation. On the top course of masonry the foundation plates of cast iron, 3 feet 6 inches square and 4 inches thick, are bedded in fireclay, to which are bolted the cast iron columns B B, Fig. 3, 17 inches diameter, for carrying the superstructure. These columns are united at the top by a cast iron ring or cornice C in segments, $3\frac{1}{2}$ inches thick, each segment having a semicircular snug cast on its under side, which when the work is joined together fits into the top of the column B, thus binding the whole of the segments into one ring.

The entire lining of the furnace inside is of refractory firebrick D, Fig. 3, Plate 63; the furnace is cylindrical on the outside and entirely cased with wrought iron plates E, $\frac{3}{8}$ inch thick at the bottom of the furnace, and towards the top of the furnace diminished in thickness to $\frac{5}{16}$ inch. This casing weighs about 30 tons and costs about £400, and is now being generally used in place of the massive stack of masonry formerly used. There are ten cast iron pillars B for carrying the super-structure, placed at a distance of 7 feet apart, except where the tapping hole is situated, where the distance is increased to 10 feet, as seen in Fig. 4, Plate 64. Brackets are cast on these pillars, Fig. 3, for the

purpose of carrying the circular pipes that convey the blast and water round the furnaces for distribution to the various tuyeres. There are five tuyeres to each furnace, one of which is shown in longitudinal section in Fig. 9, Plate 64.

At the top of the furnace a wrought iron plate cornice F is fixed, Fig. 3, Plate 63, forming the charging floor; and the two furnaces are connected by means of two longitudinal wrought iron girders 4 feet and 3 feet deep respectively, the larger one prepared to receive the wrought iron beams that form the roadway of the incline up which the materials for smelting are drawn by means of a pair of fixed horizontal engines. These girders are united by nine intermediate cross girders of wrought iron, and when covered with plates form the roadway of the charging floor, having a screen 3 feet 6 inches high running round for protection.

The throat of the furnace, Fig. 3, Plate 63, is adapted for taking off the waste gas, which is collected in a wrought iron tube G, 5 feet diameter, which extends down the throat of the furnace about 5 feet and is lined inside and cased outside with refractory firebrick 6 inches in thickness. This tube is fixed to and supported by a crown or dome built in the throat of the furnace, of specially moulded lumps of fireclay, supported by six buttresses built of the same material. The crown has six openings formed at the sides for charging purposes, and one opening in the centre, through which the gas passes into the tube G. There is the usual brick chimney at the top of the furnace, with wrought iron swing doors corresponding with the openings in the crown. The gas is conveyed from the furnace top to the boilers, hot-blast stoves, &c., by a wrought iron tube 5 feet 6 inches diameter, large enough to take off the gas from two additional furnaces; and square boxes H, Fig. 1, Plate 61, are fixed at intervals along the tube to allow for expansion. A flap valve I, Fig. 3, Plate 63, opening outwards for cleaning purposes is fixed at the end of the tube over the furnace.

Figs. 10 and 11, Plate 65, show a vertical section and sectional plan of one of the hot-blast stoves. Three of these are built to each furnace, of common brick made on the estate, lined with

refractory firebrick, and externally bound firmly together by wrought iron hoops 4 inches wide and ⅜ inch thick, placed at intervals of 3 feet. The stoves are heated by the gas being admitted at the top J, and a small fire is kept on the grate at the bottom for the purpose of ensuring that the gas is always ignited. Four flues K K, Fig. 11, pass away from the bottom of the stove to the main chimney flue L, Fig. 10, which is in connexion with the chimney stack, Fig. 1, of 180 feet height. A simple disc valve J is fixed at the top of the stove where the gas enters, to cut off the supply of gas from the stove at any time. The pipes M, through which the blast passes, consist of ten pairs to each stove, 12 inches diameter, each pair being arched at the top and united at the bottom by connecting foot-boxes, thus forming one continuous course of pipes for the blast to pass along. The blast enters on one side of the oven, and after circulating through the pipes M passes out at the other side into the main pipe N for the service of the tuyeres, as shown by the arrows. A stop valve O serves to cut off the communication of each stove with the blast main, which is 5 feet 6 inches diameter and thus forms also the blast reservoir. The temperature of the blast is from 600° to 700° Fahr., and the quantity blown by each engine is 6000 cubic feet per minute at a pressure of 3 lbs. per square inch. These hot-blast stoves have been found most effective; from the enlarged capacity of the pipes, the blast is much longer in passing through them, and consequently they are not required to be kept at such a destructive heat. The writer understands that these stoves are extensively used in Staffordshire and with the best results.

The blast is supplied by three direct-acting high pressure engines, quick moving, having air cylinders 57½ inches diameter with a stroke of 3 feet. Fig. 12, Plate 66, is a transverse section of the boiler and engine house. Two engines P are sufficient for the work of two furnaces, a third one being provided in case of emergency. The reason for separate engines being used is that in the case of an accident to the blowing engine, when only one engine is used, the whole of the furnaces are thrown idle; moreover the cost of machinery for two furnaces is much less in these engines,

taking into consideration the expensive nature of the stonework &c. required for the foundation of one large beam engine. The only foundation required for these engines is about 3 feet depth of brickwork, with a framework of timber on which to bolt the foundation plates.

The engine house is of red brick with mouldings of white brick, and presents a good appearance; the roof is formed by the water tank R, Fig. 12, Plate 66, which contains the water supply for the tuyeres, pig beds, &c. In the engine house is fixed a travelling crane S for the convenience of examining any portion of the engines; this is found a most useful appendage. The water supply is derived from the river Esk by two lift pumps having trunk cylinders $7\frac{1}{4}$ inches diameter. The boilers T, Fig. 12, Plate 66, are five in number, each 73 feet long by 5 feet diameter, of the plain egg-ended form, heated by the waste gas from the blast furnaces. They are suspended by means of cast iron bridges from the top of the boiler seats, and are fed by three donkey engines, all connected to one pipe over the boilers. The steam pressure is 60 lbs. per square inch above the atmosphere.

A steam lift is fixed in the works in the position shown in Fig. 1, Plate 61, for the purpose of raising the minerals from the line of railway to the top of the calcining kilns.

Mr. Sampson Lloyd thought the new ironworks described in the paper were a good illustration of the modern improvements that were now being generally adopted in ironworks. The blast furnaces appeared to be built according to the construction now generally in use; but for taking off the gas from the open top of the furnace a variety of plans had been adopted, and the main peculiarity of the arrangement shown in the drawings appeared to be the use of a wrought iron tube for the purpose, inserted into the top of the furnace and lined inside and outside with firebrick. That plan had

now been in use for some time at Messrs. Schneider's furnaces near Ulverstone, where the furnaces were not stopped on the Sunday, but worked continuously from the beginning to the end of the week. But where the furnaces stopped on the Sunday, as was the case at the new works now described, the alternate contraction and expansion of the firebrick was a serious difficulty to contend with, causing the firebrick to crack and become detached, and necessitating frequent renewals of portions of the lining. Moreover the usual plan had been to make the extremity of the tube, where it dipped into the materials in the top of the furnace, of cast iron, that it might have greater durability under the action of the flames arising from the gas burning out of the top of the furnace around the tube; and the cast iron tubes were generally found to last from 12 to 18 months before requiring renewal.

The circular hot-blast stoves shown in the drawings were a construction that had been in use for a considerable number of years without being open to any great objection; but they were not the kind that was generally preferred in South Staffordshire, nor had they been found the best at some of the new ironworks lately erected at different places in the North of England. The long oven had been found in practice better than the circular oven, in respect both of economy of fuel and temperature of blast obtained; and in the present instance the temperature of the hot blast, 600° to 700° Fahr., was not so high as was now generally used for hot-blast furnaces: the heat however was regulated in different districts according to the particular requirements of the iron.

With regard to the most suitable description of blast engine to be employed, there was a great variety of opinion. Where engines had to run day and night from year's end to year's end, keeping up a uniform pressure of blast, his own experience was that a large engine working with a slow motion was the most economical in the long run. The small quick running engines described in the paper were certainly the cheapest in the first instance, but he doubted whether they would be found so in working over a series of years.

Mr. T. W. Plum remarked that the gas tube inserted in the mouth of the blast furnace appeared to be carried by an arch or

false top built in the mouth of the furnace, with openings round the tube for charging the furnace; and he enquired whether that plan was not liable to difficulties from the charging holes getting stopped up occasionally by accident. He feared also some inconvenience would be caused in winter from the water getting frozen in the large open water tank forming the roof of the engine house, unless some provision were made for preventing such an occurrence.

Mr. F. J. Bramwell said he had seen the same arrangement of the gas tube in the top of the blast furnace at Messrs. Schneider's furnaces working the hæmatite iron; the tube was coated with firebrick inside and outside, in the manner shown in the drawings, and carried on six flying buttresses built in the throat of the furnace, so that the mouth of the furnace was in no way closed up except by the gas tube. He understood from the manager of the works that not the slightest trouble had been experienced with that arrangement, and that nothing could be more successful than that mode of taking off the waste gas.

Mr. E. Reynolds enquired whether the blast furnaces in the Cleveland district were worked with coal or with coke.

Mr. D. Adamson said that throughout the Cleveland district the blast furnaces were all worked with coke, and no coal at all was used in them; the same was the case in the Wear district and the North of England generally. One common feature of the ironworks in the North was the use of quick short-stroke blast engines, in place of the large long-stroke engines generally employed for blowing the Welsh furnaces, which were considered more advantageous in that district; but in his own opinion a vertical direct-acting high pressure engine with moderately long stroke was much more economical in working for supplying the blast than a heavy beam engine.

In reference to the method now described of taking off the waste gas from the top of the blast furnace, leaving the space round the gas tube open for the escape of the superfluous gas, he questioned whether that plan went far enough in the matter: for if the gas could be employed with advantage for so many purposes, for heating

the steam boilers and hot-blast stoves and calcining the ironstone, he thought none of it ought to be left to escape from the mouth of the furnace, but the whole should be collected and saved. The gas might for instance be more generally employed than at present for calcining the ironstone, for which he thought it was particularly suitable, giving the means of calcining all the material uniformly. The great aim in blast furnaces was to get uniformity of heat in all parts at the same level, and an important step would be effected in that direction if the ironstone were uniformly calcined beforehand by the application of the waste gas, and then conveyed direct to the blast furnace without having to lie exposed to rain and weather, which he believed would obviate some of the difficulties that had at present to be contended with in the blast furnace.

The blast furnaces described in the paper must he thought be working well to produce the make that had been stated of 250 tons of iron per week from each furnace. That was a very large production for the Cleveland district, because to produce one ton of iron from the Cleveland ore required $3\frac{1}{4}$ tons and upwards of ore, 15 or 16 cwts. of limestone, and 27 or 28 cwts. of coke; making nearly $5\frac{1}{2}$ tons of material per ton of iron, so that an enormous quantity of material had to pass through the blast furnace in order to produce 250 tons of iron per week. In the hæmatite district on the other hand the quantity of ironstone did not exceed $1\frac{3}{4}$ tons per ton of iron made, and the quantity of limestone was only 4 to 5 cwts., while the coke required was from 17 to 25 cwts.; making only about 3 tons of material per ton of iron.

The working conditions of the blast engines must always depend in a great measure on the pressure of blast that was employed, which had been stated in the paper to be 3 lbs. per square inch at the Grosmont furnaces: but at another of the ironworks in the Cleveland district, Messrs. Warners and Co.'s, Norton Furnaces, near Stockton-on-Tees, he found that the pressure had been reduced from $2\frac{3}{4}$ lbs. down to only $\frac{1}{2}$ lb. per square inch, and that the make of iron from the furnace was rather increased, while the work done by the blast engine was very much less. This was such a change upon the current practice in blast furnaces as to be worthy of

careful consideration. The size of the tuyeres had at the same time been increased from 3 inches to 6 inches diameter, admitting a greater volume of air to the furnace, and they would have been made still larger had they not been limited by the size of the blast main, which was only 9 inches diameter. It was intended however to enlarge the tuyeres further to 9 inches diameter, and reduce the pressure of blast from $\frac{1}{2}$ lb. to $\frac{1}{4}$ lb. per square inch. At those works the ore used was the Cleveland ironstone, and also the Rosedale magnetic ironstone, the only magnetic iron ore yet discovered in the Cleveland district.

Mr. T. W. PLUM asked how the quality of the iron produced was affected by the reduction of pressure of the blast. It was generally understood that a reduction in pressure of blast improved the yield of the furnace, that is the quantity of iron obtained from the ironstone, and also the quality of the iron, but reduced the total make of the furnace in quantity.

Mr. D. ADAMSON said that the result of reducing the pressure of blast had been favourable on the whole to the brand of iron, as the reduced pressure contributed materially to keep the furnace steadily on foundry quality of iron, without so much liability to fluctuation of quality under atmospheric changes as in other furnaces with a higher blast, where a cold east wind or rain would bring the quality down from No. 1 to No. 3 immediately. At the works he referred to the engine power was not yet fully developed, and the volume of air at present supplied was only about one half more than at the ordinary higher pressure. The blast engines were horizontal, with a moderately long stroke; but he considered the air cylinders never worked so well in a horizontal as in a vertical position, as the vertical air cylinders had less wear, and were less exposed to grit and dust accumulating on their rubbing surfaces.

Mr. F. J. BRAMWELL remarked that, in reference to the question of taking off only part of the waste gas from the blast furnace, it did not follow that because so much advantage had been found in taking off part of the gas therefore the whole of it ought to be taken off: for he believed the surplus gas left to burn out round the gas tube was not to be considered as wasted, since a certain amount

of combustion was wanted in the mouth of the furnace to prepare the charges of ore as they were thrown in, by heating them; and if there were no combustion in the furnace mouth, that preliminary operation would be lost and the quality of the iron made would be impaired. Moreover the open space left round the gas tube obviated all difficulty in charging the furnace, the materials being filled in through that space just in the same manner as in an ordinary open-topped furnace. At Messrs. Schneider's works near Ulverstone all the engine power and hot-blast stoves for the entire works were supplied by taking off only a portion of the gas, and therefore there was no use in trying to take off more, while there might on the contrary be harm in doing so. At those works also exhausting fans were used to aid in drawing off the gas from the blast furnaces; and at some ironworks in France an arrangement of collecting troughs was added to catch the dust that was brought down with the gas taken off.

With regard to the make of the present furnaces, he was glad attention had been called to the large proportion of ironstone, limestone, and coke, that was required for producing the 250 tons of iron per week; because in estimating the duty of a blast furnace it was necessary to take into account not merely the actual production of iron per week, but also the nature of the materials employed, and the relative quantities consequently required to produce a ton of pig iron. In the most favourable case that he knew of, where the hæmatite ore was smelted, the make had amounted to as much as 600 tons of pig iron per week from a single furnace, owing largely to the small proportion of materials required in working that particular ore.

Mr. J. Fernie observed that another reason for leaving the mouth of the furnace open all round the gas tube was that, if the top were all closed in for taking off the whole of the gas, there was more liability to injury occurring in the event of any explosion of the gas; but the open space left round the gas tube in the present arrangement acted as a permanent safety valve, through which the force of an explosion would find ample vent without any mischief being done.

Mr. Sampson Lloyd remarked that at ironworks having two or three blast furnaces in regular work the production of gas from the furnaces was more than was wanted at present, unless some means could be found out for making the gas available in the puddling and heating furnaces, in which case it might perhaps all be made use of. But while the gas was employed only for raising steam for the blast engine and heating the hot-blast stoves, the gas given off from one or two furnaces was quite sufficient to supply the heat for blowing four or five furnaces, and therefore the gas from the remainder of the furnaces must all be wasted at present, and there would be no use in closing in the tops of the furnaces in order to take it off. Moreover the applicability of the close top depended much on the quality of the materials employed in the furnace. Where a very hard coke was used and it was not necessary to be particular as to the quality of iron made, a close-topped furnace might be found satisfactory: but where a soft coke was employed and it was of particular importance that a good quality of iron should be maintained, the open top must be adhered to, in order to avoid interfering with the working of the furnace. For though a blast furnace had the appearance of being so rough in working, it was in practice most sensitive to the slightest variations of circumstances; and the result of many years' experience with close-topped furnaces had been that it was found impossible to ensure making the best iron continuously when the top of the furnace was entirely closed in for taking off the gas. The method now shown of taking off the gas from open-topped furnaces was really so simple and so effective that there was no further advantage to be gained by closing in the top of the furnace; and he thought the open-topped plan would be found applicable to blast furnaces under all circumstances of working, without detriment to the make of iron. With the open top explosions of gas were not at all to be feared, as regarded the furnace itself; and with a proper provision of safety valves along the gas main there was no risk whatever, as an explosion produced no further effect than merely a "pop" as it was called by the workmen.

The theory of working the blast furnaces with a low pressure of blast was by no means a new one. In one of the earliest papers

read before the Institution the fan blast had been advocated in place of the blowing cylinder for blowing blast furnaces. But experience had all tended in the contrary direction; for with common materials in the furnace it was found that, with a low blast pressure of only 1 to $1\frac{1}{2}$ lbs. per square inch, not only was the yield of iron obtained much less in quantity, but the working of the furnace was generally not more economical than with the ordinary blast of 3 to $3\frac{1}{2}$ lbs. pressure per square inch. For producing the blast his own experience for a number of years led him to prefer the long-stroke large blowing engine as superior to a small short-stroke engine running at a high speed.

Mr. J. Fernie observed that the length of the boilers described in the paper, 73 feet, appeared to him great, and much beyond what was generally employed.

Mr. D. Adamson said the tendency in the North of England was to increase the length of boilers when heated by the waste gas from blast furnaces, and he had recently made some for that district as long as 85 feet and 5 feet diameter, each being supported by 20 suspension rods from cast iron beams over the top of the boiler. It must be borne in mind that in boilers heated by the waste gas from blast furnaces the products of combustion passed off at a comparatively low temperature but were large in quantity, and a long length of flue under the boilers was therefore necessary, with a large flue area, in order that the heat might be more effectually absorbed. He was not aware of any serious objection to long boilers in working, when adapted for this purpose; nor were they more expensive in proportion to their heating surface than boilers of ordinary length. The adoption of drilled instead of punched holes for the rivets was particularly desirable, two plates being drilled together as they had to be rivetted, so as to ensure sound and good workmanship with the greatest strength; and having himself made from 120 to 150 boilers with drilled rivet holes, for working at pressures varying from 80 to 160 lbs. per square inch, he was satisfied that drilling was the only true and satisfactory system for manufacturing high pressure steam boilers of any class, and for ensuring good working boilers with uniform strength at the joints.

Mr. W. Richardson said they had five long boilers at Messrs. Platt's works at Oldham, 40 feet long by 5 feet diameter, fired underneath, made with punched rivet holes; and he had found the joints at the bottom were liable to crack between the rivet holes, partly from the iron having been strained by the punching, and partly because of the unequal expansion in such long boilers, the effect of which became of course concentrated at the weakest part. He had known these cracks extend to a length of even 2 feet along the line of rivets before any leakage began; but as soon as a leak was observed the men were instructed to open all the safety valves to let off the pressure, these boilers being heated by the waste heat from puddling and ball furnaces, so that the fires could not be hastily removed. The boilers were egg-ended working with 50 lbs. steam, and in order to prevent risk of the transverse joints parting across the bottom of the boiler, he had put in two long bars inside the bottom of the boiler, tying the ends together; and had also built a firebrick arch over the fire, extending back as far as the bridge, to protect the bottom of the boiler from the direct intense heat of the fire. Three cases had occurred where some of the bricks had become broken and had fallen out, and the plates though made of Low Moor iron and not left uncovered by the water became heated red hot and blown out so thin that the water broke through and put the fire out.

Mr. I. Smith enquired how the feed water was introduced in those long boilers.

Mr. W. Richardson replied that the feed water was supplied at the opposite end to the furnace, and was brought in at the bottom of the boiler.

Mr. I. Smith thought that mode of introducing the feed water was one of the causes why the plates had been found to crack along the lines of rivets at the bottom; for in some boilers 35 feet long at copper works in South Wales he had found that when the feed was sent in cold along the bottom of the boiler, or colder than the water in the boiler, the bottom plates became strained longitudinally by being exposed to the heat of the fire outside and the cool feed water inside; and a deposit of calcareous matter was also formed along

the bottom, so that the plates were very liable to get burnt. The injurious effect of deposit was forcibly shown by holding a tin pot of water over a smith's fire, when the bottom could not be melted out, however thin; but if there were any sediment upon it, then it was burnt out directly. One of the long boilers of 35 feet length had now been reduced to 25 feet length and the firegrate proportionately diminished, and the same quantity of steam was found to be produced with considerably less consumption of fuel; new boilers had since been put down only 13 feet long and $6\frac{1}{2}$ feet diameter with internal flues, and he thought it was a step in the wrong direction to prolong boilers to such lengths as had been mentioned. The feed also had been altered to enter only 4 inches below the water line, at the end furthest from the fire; and it was sent in horizontally so as to diffuse the water through the boiler and avoid an accumulation of deposit at one particular place. With this arrangement and heating the feed water before its entrance into the boiler they had never been troubled with burning a plate since the alteration was made.

The fuel used for these boilers was the semi-anthracite coal of South Wales, and a brick arch had formerly been put in over the fire to protect the boiler at that part from injury. But the boiler itself was now placed at a greater height above the firegrate; for a large space was needed for the proper combustion of the gases evolved from the fuel, and it was a mistake to suppose any loss of heat could arise from allowing too much room under the boiler; on the contrary, the furnace ought to be all one mass of flame under the boiler, without any smoke or soot, and he thought there was generally a loss of heat from setting the boiler too low, both in the South Wales and the South Staffordshire districts. The fire bridge too was usually brought up too close to the bottom of the boiler, which was a frequent cause of injury to the plates at that part by the severe impinging of the flame upon them; and he had found the area of passage at the bridge ought to be at least as much as 25 square inches per square foot of grate surface for the Staffordshire coals, according to the rule given by Murray. Attention had frequently been drawn to the importance of

observing this requirement by the Manchester boiler association. Where boilers were heated by gas, as at the ironworks described in the paper, it was important to take care that the gas was burnt in the proper way under the boilers, by means of a number of burners distributing it over a large area, instead of being all burnt in a large mass at one spot. He was now erecting a furnace for generating gas to heat the boilers at his works in Birmingham, being satisfied of the advantages that would result from that mode of heating instead of ordinary coal fires.

Mr. W. Richardson said in the boilers he had described the water was not fed in cold, but was heated to 212° Fahr. before admission into the boiler. The mode of admitting the feed had also been altered, and it was now sent in through a rose pipe about 12 inches below the water line at the far end of the boiler, so that the deposit might take place as far as possible from the fire. The plates of the boilers were $\frac{1}{2}$ inch thick, in order to be strong enough to carry the pressure of 50 lbs. with safety; but that thickness was rather too great for a ready transmission of the heat. As to the liability of the plates to get burnt where covered with deposit, it was not only where the deposit was very thick that this risk was incurred; for with 3 feet depth of water over the plates he had known them burnt even with less than 1-16th inch thickness of deposit on them.

Mr. S. Bastow observed that the large majority of boiler explosions that took place occurred with the Cornish boilers with an internal flue, where any deficiency of water quickly left the top of the flue bare: and the plain cylindrical boiler was attended with much less risk of explosion, because the bottom plates exposed to the fire remained covered with water so long as there was any water at all in the boiler. If the bottom had to be strengthened by longitudinal tie bars, as had been mentioned, this showed he thought that there must be some defect in the working of the boiler or some improper impingement of the flame to cause so serious a strain upon the bottom plates. The Cornish boiler was no doubt more economical; but on account of its greater safety and simplicity he thought the long plain cylindrical boiler was better adapted for such

situations as the ironworks described in the paper, where there was plenty of room for the boilers and fuel was cheap, or waste gas available from blast furnaces. He believed there were a large number of the plain cylindrical boilers longer than 73 feet; they were suspended by overhead bearers in the manner shown in the drawing, so as to be quite free for expansion and contraction without injury to the brickwork. These long boilers he had no doubt would continue in general use for such situations, as there were no other boilers so economical in construction, so durable in work, or so little liable to explosion.

Mr. F. J. Bramwell remarked that boilers heated by the waste gas from blast furnaces might certainly be expected to have an advantage in durability over similar boilers worked with ordinary coal fires; for it had been observed in Mr. Siemens' regenerative gas furnaces that the gas took an appreciable length of time to become sufficiently mixed with air for its complete combustion, and consequently the combustion was not confined to one place under the boiler, but there was a gentle combustion all over the bottom of the boiler, which must be highly conducive to its durability.

Mr. D. Adamson said he had had a large number of Cornish boilers under his observation and had never had any accident with them, although if the feed water were introduced in an improper manner the plates might unquestionably become burnt and the joints strained. But the plain cylindrical boiler he considered wasteful in fuel, and on that account inapplicable for many purposes, since the evaporative duty was never above 6½ lbs. of water per lb. of coal: whereas a good Cornish or tubular boiler, with proper room left for the circulation of the water, evaporated from 10 to even 12 lbs. of water per lb. of coal. In the explosions that had occurred with Cornish boilers he believed it had generally been the outer shell which had first been rent asunder, instead of the internal flue first collapsing as was usually supposed; for a great source of destruction in such boilers was the inequality of temperature to which they were subjected in different parts, owing to defective circulation of the water or bad arrangement of the flues surrounding the boiler; and more injury arose from the bottom of

the boiler being too cold than from the top of the internal flue being too hot. Hence many boilers under such conditions suffered much in getting up steam, and he knew of boilers worked continuously day and night throughout the week which had lasted much longer than similar boilers fired only one day in the week and thus doing a far less amount of work than those continuously in use. He therefore believed the Cornish boiler, when properly arranged in these respects, was both the safest and most economical construction of steam boiler.

The CHAIRMAN enquired what was the mode of admitting the gas for burning under the boilers, where the waste gas was brought down from the blast furnace.

Mr. SAMPSON LLOYD replied that at the Old Park Iron Works, Wednesbury, where the gas was taken off from an open-topped furnace in the manner described in the paper, the gas was simply turned into the fireplace of the boilers through a single opening a little before the end of the boiler, so that it might become sufficiently mixed with the atmospheric air. So far as could be seen, the gas was completely ignited and thoroughly consumed during its passage under the bottom and through the flues of the boiler.

The CHAIRMAN observed that, in reference to the enlargement of the tuyeres and the reduction of the pressure of blast, this had been proposed by Mr. Fairbairn as long ago as 1835, with the use of the fan blast for the purpose instead of a blowing cylinder. But as to the yield of the furnace being the same, whether it were worked at a pressure of $2\frac{1}{2}$ lbs. per square inch or $\frac{1}{2}$ lb., that certainly appeared contrary to the experience of the iron trade; and it would be necessary to learn in connexion with any such statement whether there was anything peculiar in the minerals employed or in the size and construction of the blast furnace where the lower pressure of blast was used. In the South Staffordshire district he understood it was generally thought impossible to get the blast sufficiently into the heart of the furnace unless a high pressure of blast was employed for the purpose. With regard to utilising the excess of gas produced from the blast furnaces beyond

what was required for the boilers and hot-blast stoves, at some of the ironworks on the continent it had now been customary for many years to work a portion of the puddling and heating furnaces with the waste gas from the blast furnaces, on account of the fuel being much dearer there than in this country, so that it was necessary to economise the waste heat as much as possible. All such questions however must be solved by the experience of individual works or districts: the closed top that had been found successful for blast furnaces in the North of England would perhaps not be suitable for Staffordshire or South Wales, and in these districts it might be indispensable to leave the furnace top open for part of the gas to burn out.

He proposed a vote of thanks to Mr. Coulthard for his paper, which was passed.

A vote of thanks was moved and passed to the Chairman, the Local Committee, and the Honorary Local Secretary, Mr. William Stubbs, for the excellent arrangements they had made for the meeting of the Institution in Liverpool; and also to the Liverpool Town Council for their kindness in granting the use of St. George's Hall for the purposes of the meeting.

The Meeting then terminated. In the afternoon the Members were conveyed by special steamer, granted for the occasion by the Cunard Steam Ship Co. through the kindness of Mr. MacIver, to the Canada Dock, where they inspected the large dock gates, swing bridge, and capstans, with the hydraulic machinery employed for working them, and also the "Asia" and "Australasian" steam vessels lying in the dock. They afterwards visited Messrs. Laird's iron shipbuilding yard, the Woodside Landing Stage, the Birkenhead Float, and the Hydraulic Chain Testing Machine.

In the evening the Members and their friends dined together in St. George's Hall, in celebration of the meeting of the Institution in Liverpool.

On Thursday, 6th August, an Excursion of the Members took place to the Ravenhead Plate Glass Works at St. Helen's, the Kirkless Hall Coal and Iron Works near Wigan, and the Ince Hall Collieries near Wigan, where they were handsomely entertained by Messrs. Pearson and Knowles. On returning to Liverpool the Members visited St. George's Hall in the evening, to inspect the arrangements for the mechanical ventilation and warming of the building, which were shown in operation by Mr. Mackenzie.

On Friday, 7th August, an Excursion was made by the Members to the London and North Western Railway Locomotive Works and Rail Works at Crewe, where a number of Bessemer steel rails were rolled; and also to Parkside, where the Water Trough for filling locomotive tenders whilst running was shown in operation. The Members were handsomely entertained at the Crewe works by Mr. Ramsbottom; and on both days the Excursions were made by special train granted to the Members for the occasion by the kindness of the London and North Western Railway Company.

PROCEEDINGS.

5 NOVEMBER, 1863.

The GENERAL MEETING of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Thursday, 5th November, 1863; SAMPSON LLOYD, Esq., in the Chair.

The Minutes of the last Meeting were read and confirmed.

The CHAIRMAN announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Annual Meeting.

The following Members were nominated by the meeting for the election at the Annual Meeting:—

PRESIDENT.

ROBERT NAPIER, ...	Glasgow.

VICE-PRESIDENTS.

(*Six of the number to be elected.*)

CHARLES F. BEYER, ...	Manchester.
WILLIAM CLAY, ...	Liverpool.
EDWARD A. COWPER, ...	London.
THOMAS HAWKSLEY, ...	London.
ROBERT HAWTHORN, ...	Newcastle-on-Tyne.
SAMPSON LLOYD, ...	Wednesbury.
HENRY MAUDSLAY, ...	London.
JOHN RAMSBOTTOM, ...	Crewe.
C. WILLIAM SIEMENS, ...	London.

COUNCIL.

(Five of the number to be elected.)

Alexander Allan, ...	Perth.
John Anderson, ...	Woolwich.
Peter D. Bennett, ...	Westbromwich.
Frederick J. Bramwell, . . .	London.
Charles Cochrane, ...	Dudley.
Benjamin Fothergill, ...	London.
Thomas Greenwood, ...	Leeds.
James Kitson, ...	Leeds.
Walter May, ...	Birmingham.
John Vernon, ...	Liverpool.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

John James Birckel, ...	Liverpool.
Julius Boeddinghaus, ...	Elberfeld, Prussia.
Robert Clayton, ...	Preston.
Alfred Davy, ...	Sheffield.
Joseph Hall, ...	Gratz, Styria.
Frank Holt, ...	Manchester.
Sturges Meek, ...	Manchester.
John Musgrave, Jun., ...	Bolton.
Walter Montgomerie Neilson, .	Glasgow.
Thomas J. Perry, ...	Bilston.
Samuel Rigby, ...	Warrington.
Henry Sharp, ...	Bolton.
William Ford Smith, ...	Manchester.
William Hugill Walker, . . .	Sheffield.
William Wallace, ...	Liverpool.
John Charles Wilson, . . .	London.
Francis Wise, ...	London.
Owen Wright, ...	Oldbury.

HONORARY MEMBERS.

JOHN FAIRBAIRN, ...	Leeds.
GEORGE EMMERSON FORSTER, . .	Washington.
WILLIAM HACKNEY, ...	Birmingham.
WILLIAM NICHOLS, . . .	Burton-on-Trent.
ARTHUR RIGG, ...	Chester.
THOMAS R. STOREY, . . .	London.

The following paper was then read:—

DESCRIPTION OF THE CORNISH PUMPING ENGINE WITH WROUGHT IRON BEAM AND THE PIT WORK AT CLAY CROSS COLLIERY.

By Mr. WILLIAM HOWE, of Clay Cross.

At the commencement of the working of the Clay Cross Colliery the upper seams of coal were drained by the Clay Cross railway tunnel; but as the lower seams were sunk to and worked, the water could no longer run into the tunnel, and gradually increased in quantity until it became necessary first to put in pumps of small size worked by the winding engines then in use on the colliery, which were sufficient for draining the works for some years. Afterwards as the works extended further, one pump after another was added, until there were altogether six pumping stations, at two of which were independent pumping engines of 40 horse power each. The water still following to the dip of the measures, it was found that either more pumping power must be added in the same way that it had been increased from the commencement, by putting down more engines, or else a single large pumping engine must be erected to drain the whole of the works, which had extended to an area of several hundred acres and a depth of 420 feet. After much consideration it was determined to erect a single large pumping engine on the Cornish principle, to pump the whole of the water at one point of the colliery. When this was completed it at once threw out of use seven sets of pumps and engines requiring several enginemen to look after them; and saved much expense in repairs, which had been continually necessary at one or other of the several pumping stations.

In adopting this plan of pumping it had to be taken into consideration that the drainage of the whole colliery would be

dependent on one engine alone, instead of on several independent engines distributed at various points of the works; but as the working of the minerals went on increasing, the water partially left the pumps at the upper part of the works and ran down to the lower level, necessitating increased pumping power at a greater depth. This led to the conclusion that a central pumping station would be the most effectual and convenient; and the general result of experience showed that the Cornish pumping engine was most to be relied on for pumping from a considerable depth, and when well constructed was least likely to require repairs. The result has completely carried out these anticipations, as the new engine has maintained the entire drainage of the colliery for the last three quarters of a year, and has proved itself completely satisfactory in requiring no repairs, and has effected a great saving in cost of enginemen and repairs as well as in fuel and stores. It has to be remarked also that the plan of having pumps in connexion with winding engines, as was previously the case, involved the disadvantage that the engines when winding were not so perfectly under control for starting or stopping at particular points when required, on account of being burdened with the irregular load of the pumps: there was also the objection of having to disconnect the ropes when it was required to run the engine for pumping alone. A rotary pumping engine is also exposed to the dangers that inevitably arise with a pump, from an obstruction getting under the suction clacks and causing the pump to miss its stroke; or from the pump being only partially filled with water, so that when the plunger meets the water at half stroke, or at any other point short of the top, the concussion produced is so great that some portion of the machinery must give way.

The new Engine, forming the subject of the present paper, is an ordinary Cornish pumping engine, erected by the Butterley Company; and is shown in Fig. 1, Plate 67, which is a side elevation of the engine and a section of the house. The cylinder A is 84 inches diameter with a stroke of 10 feet. The engine house is a substantial building, on a foundation of concrete 18 inches thick. The cylinder

pillar B is built of large ashlar stones set on the concrete, and is $18\frac{3}{4}$ feet high and 10 feet thick, running the full width of the house and built into the side walls. A pair of heavy cast iron girders C C, shown black in section, run underneath the cylinder pillar and extend under the side walls of the house, the holding-down bolts of the cylinder passing through them. The beam wall D, which extends across the house and unites with the side walls, is also built of large ashlar stones up to the level of the cylinder pillar, and is 8 feet thick; on the top of this work a cast iron plate E is laid, 7 feet wide, extending nearly the full width of the engine house; the beam wall is then built up of brick to within $3\frac{1}{4}$ feet of the bedplate for the main plummer blocks to rest upon, and is then finished with two courses of ashlar stone. Eight large tie bolts pass down through the spring-beam boxes, the bedplate, and the plate E at the bottom of the brickwork, securing the whole in one solid mass. The rest of the engine house is built of brick with stone quoins.

The top nozzle F, Fig. 1, Plate 67, contains the regulating, steam, and equilibrium valves: the regulating and equilibrium valves are each 12 inches diameter, and the steam valve 14 inches. The bottom nozzle G contains the eduction valve, which is 18 inches diameter. All the valves are on the ordinary double-beat principle, of massive construction and made of gun-metal. The top and bottom nozzles are connected with two side pipes H, each 12 inches diameter, through which the steam passes from the top to the underside of the piston, forming a perfect equilibrium. The cylinder cover is double, having a false cover with a space between. The cylinder is not made with the steam-jacket usually employed in Cornish pumping engines, but it is covered with wood and dry hair felting; an air space of 5 inches is left between the outside of the cylinder and the first covering of rough 1 inch boards; outside of these is placed about 1 inch thickness of felt, and outside that a cleading of 2 inches thickness: the whole having sufficient non-conducting power to keep the engine house remarkably cool. The metal of the cylinder is $2\frac{1}{4}$ inches thick, with flanges in proportion well bracketed, and weighs upwards of 11 tons. The

piston has metallic packing, two outer rings and one inner one, all of cast iron; eight springs are placed inside the inner ring, with pins and nuts for adjustment.

There are two plug rods I, Fig. 1, Plate 67, one carrying the tappet to shut the steam valve, which may be varied to work to any degree of expansion, and also a tappet to work the cataract J for opening the steam, eduction, and injection valves; the other rod carries the tappets to close the eduction, equilibrium, and injection valves, and also a tappet to work the cataract K for opening the equilibrium valve. Generally, it is believed, Cornish pumping engines have only one cataract J, to open the steam, eduction, and injection valves at the conclusion of the outdoor stroke; but in the present case the writer preferred having a second cataract K to open the equilibrium valve at the conclusion of the indoor stroke, so as to have a pause at each end of the stroke, before the opening of the equilibrium valve as well as before the admission of the steam, in order to allow ample time for the pump valves to close completely.

The air pump and condenser are placed within a cast iron cistern L, Fig. 1, Plate 67, $10\frac{3}{4}$ feet long, 7 feet wide, and $11\frac{1}{2}$ feet deep, bolted down upon two cast iron girders placed on a heavy ashlar stone and brick foundation. The foot and delivery valves and also the bucket valve are composed of india-rubber discs, with brass grid faces, having a guard above to prevent them from rising too high. The air pump bucket is packed with hemp, as is generally the case in such engines; and the injection valve is fixed on one side of the condenser, inside the cistern. The injection pipe is a 4 inch pipe tapering to 3 inches diameter at the end, and is set pointing in such a direction as to throw the water against the side of the condenser, whereby it is distributed so as to meet the steam. The water in the condensing cistern is kept at a temperature of 50° Fahr., the temperature of the hot well being 113°.

The engine Beam M, Fig. 1, Plate 67, is of wrought iron, designed and made by the Butterley Company, and is shown in detail to a larger scale in Figs. 2 to 6, Plates 68 and 69. It is made of two wrought iron slabs M M, one on each side, each slab being

rolled in one piece 2 inches thick throughout, 36½ feet long over all, 7 feet 1 inch deep in the middle and 3 feet 4 inches deep at the ends. Each slab weighs upwards of 7½ tons, and the total weight of the beam is about 33 tons. The two wrought iron slabs are stayed and bolted together by large cast iron distance pieces N N with broad flat ends, the holes being bored and the bolts turned for bolting the slabs to the ends of the distance pieces. There is also a strong cast iron centre piece O, bored for the main centre gudgeon to pass through, Fig. 4, and keyed upon the gudgeon. Each end of this centre piece is turned, and has a projecting boss P also turned; the two large wrought iron slabs are bored to fit these bosses, and cast iron washer plates also bored are put on outside; and the whole is securely bolted together with twelve bolts on each side, turned and fitted into holes bored to receive them. The beam is stiffened on the lower side by a wrought iron plate Q, 12 feet long and 1 inch thick, underneath the main centre, connecting the two wrought iron slabs, which are 4 feet 1½ inch clear apart; the plate Q is rivetted to the slabs by two heavy angle irons. The gudgeons, excepting the main centre, are turned and fitted into holes bored in the sides of the beam, as shown in Fig. 6, having a cast iron washer plate bolted on the slabs both outside and inside to give a longer bearing, the washer plates being bolted through the beam slabs with bolts turned and fitted accurately into bored holes. The gudgeons are rivetted over the outside washers, which are slightly countersunk for the purpose, and a key is put through before this is done to prevent the gudgeon from turning. The beam thus constructed is perfectly stiff, and no lateral vibration can be perceived; it is altogether a complete success.

The parallel motion R, Fig. 1, Plate 67, is placed inside the beam slabs M; it is of the ordinary construction, very substantial and got up bright. The crosshead is a massive block of wrought iron through which the piston rod passes loose; the rod is 8 inches diameter and is secured in the crosshead by two half rings of 1 inch larger diameter, fixed in a recess turned in the top of the rod, the hole in the crosshead being also bored out to 9 inches diameter for half the length from the top; so that, should the piston strike

the bottom of the cylinder, the piston rod would slide up free through the crosshead.

The engine is always started with high pressure steam without a vacuum, the steam and eduction cataract J, Fig. 1, Plate 67, being secured by a pin so that the valve catches cannot be lifted by the cataract. The regulating valve is opened by the handwheel and screw; the eduction and injection valves are opened by the handle; and the steam valve is opened by placing the foot in the stirrup on the rod. The engine thus makes the indoor stroke, and after a few strokes a vacuum is produced, and the engine regulated to the proper length of stroke by the regulating valve. The cataract J is then released so that it may liberate the valve catches; and the engine then works the desired length of stroke so long as the steam in the boilers remains at about the same pressure. The cataracts J and K which are charged with water are of the ordinary description, having a working barrel with a ram in it, which is placed inside a small circular cistern; the working barrel has only one clack or valve, which opens inwards. The outlet for the water is through a small orifice, the opening of which is regulated by raising or lowering a plug by means of a screw and handle. The speed of the engine is thus regulated by lengthening or shortening the interval between each stroke, so that it may be worked from a minimum speed of only one stroke in three or four minutes up to a maximum speed of about eight strokes per minute. The engine does not regularly make the full stroke of 10 feet length, but averages about 9 feet 7 inches; and the speed seldom exceeds four strokes per minute, the piston in that case attaining an average speed of about 76 feet per minute. The usual speed of the piston during the indoor stroke is about 290 feet per minute, and the outdoor stroke occupies about double the time of the indoor stroke. The speed of the indoor stroke varies of course according to the degree of expansion: when the steam is admitted to the cylinder at a higher pressure and cut off at about two thirds of the stroke, the indoor stroke is completed in about $1\frac{1}{2}$ seconds, or the piston travels at the rate of about 400 feet per minute. But when this is the case the concussion of the pump rods in the shaft is so great that it is not desirable to work at such a high degree of expansion at present.

The boilers are of the plain cylindrical form with hemispherical ends, and fired underneath: they are four in number, each being 35 feet long and 5 feet diameter. The steam stop-valves are placed on a dome 4 feet high and $2\frac{1}{2}$ feet diameter, rivetted on the top of each boiler; two horizontal steam receivers, each 13 feet long and 3 feet diameter, united by an expansion joint, form the main steam pipe, each passing over two boilers and connected with the boilers by elbow branches jointed on the stop-valve boxes: so that any condensation which may take place in the steam pipes between the boilers and the engine will run back into the boilers. It is intended to cover these steam receivers with dry hair felting and sheet iron, and also to place a house and roof over the boilers, in order to prevent radiation and condensation. The flues run from the fires up one side of the boilers and down the other side, being separated by a centre wall; and the flues of two boilers meet in one main flue leading to the chimney which is 101 feet high. The boilers are supplied with water from the hot well by a donkey engine.

The depth of the pit shaft is 418 feet, and the general arrangement of the pit work is shown in Figs. 7 and 8, Plates 70 and 71, which are vertical sections of the pit shaft with the pumps in elevation. The black portions represent the different seams of coal passed through in sinking.

A large stone 18 inches thick is bedded at the bottom of the shaft for the windbore of the bucket pump to rest upon. The remainder of the shaft bottom is filled in with hard burnt bricks and Barrow lime, forming a level bottom, so that the "sump" S, Figs. 7 and 8, may be cleaned as easily as possible when required. The bucket set of pumps, shown to a larger scale in Figs. 12 to 17, Plate 73, is 160 feet from the bottom of the windbore to the delivery pipe T, Figs. 7 and 10, the working barrel being 18 inches diameter and made for a 10 feet stroke. The pipes are 19 inches diameter, so that the bucket may easily be raised up through them if necessary. The bucket when at the top of the stroke is about 25 feet from the bottom of the windbore. The suction

clack A, Fig. 13, is $10\frac{1}{2}$ feet from the bottom of the windbore, and is shown enlarged in Figs. 18 to 21, Plate 74: it is made of brass, with wrought iron lids faced with leather, shown black in Figs. 18 and 19, working on a pin B which acts as the hinge. The hole through which the hinge pin passes in the clack is slightly oblong vertically, as shown in Figs. 18 and 20, allowing the clack falls to lift vertically about 1-8th inch as they open. The hinge pin B is kept in its place by the clack door, and when the door is removed the pin can be drawn out and the clack lids changed in a few seconds.

The bucket, shown enlarged in Figs. 16 and 17, Plate 73, is made of brass, and the lids of iron faced with leather, like those of the clack; and the hole in the bucket rod through which the hinge pin B passes is also slightly oblong, to allow the lids to lift a little in opening; the pin is secured endways by a cotter, but should the cotter by any means slip out of its place, the hinge pin cannot get out, so long as the bucket is in the working barrel. The top part of the bucket is flanged out to fit the working barrel, and the hoop C at the bottom of the bucket also nearly fits the barrel. The leather, shown black in Fig. 16, is placed on the bucket in the usual manner, and covered by the hoop C below: by this means it is hoped to prevent the leather from wearing out on one side of the bucket, as sometimes occurs, by the flange on the top of the bucket and the hoop on the bottom keeping the bucket in a truly central position in the working barrel in this case, the leather acting solely as the water-tight joint between the flange on the top and the hoop on the bottom of the bucket.

The bucket spears are 9 inches square, fixed on the side of the main spears by strong wrought-iron clamps. They are made of pitch pine with butt joints, secured by four wrought iron strapping plates to each joint, the two side ones being 14 feet long and the other two 12 feet long: holes are bored in these strapping plates to a gauge, and the outside of the plates are faced down to form a true bearing for the nuts and bolt heads. The holes in the plates next the bolt heads are bored 1-16th inch larger in diameter than those next the nuts, in order to allow the bolts to be driven in easily until they are nearly up to the head, when they are driven tightly

in; and the bolts also are turned to a gauge of 1-16th inch larger diameter for 1¼ inch length underneath the head, in order to get the full bearing through the hole in the plate. This mode of fixing gives an advantage also in getting the bolts out whenever repairs are required, because after they have once been moved they can then easily be driven out.

This bucket pump delivers into the drift D, Figs. 8 and 10, Plates 71 and 72, which is carried forward to the well E, whence the lower plunger pump F takes the water and delivers it at the drift near the top of the pit.

The lower plunger pump F, Figs. 7 and 8, Plates 70 and 71, is shown in section enlarged in Figs. 22 to 25, Plate 75. The clacks are of brass and fitted up the same as the clack already described in the bucket pump, as shown in Plate 74. The plunger G is 18 inches diameter, and the stuffing-box H of the plunger is fixed on the top of the cylinder so that it will admit of easy removal in case of wear or breakage. The rising main I is 19 inches diameter. This plunger pump forces the water about 270 feet from the bottom of the windbore in the well E, Figs. 7 and 10, to the delivery at the drift near the top of the shaft. The pump is carried on the substantial oak bunting J, which is 2 feet 8 inches square and 16 feet long, resting on a solid bearing of more than 4 feet length at each end, as seen in Fig. 10, leaving the middle unsupported part little more than 7 feet in length. The water raised by this plunger pump from the bucket pump below is not fit to be used for the boilers or condenser on account of its corrosive quality and the impurities it contains; it is therefore allowed to run away.

The upper plunger pump K, Figs. 7, 8, and 9, Plates 70, 71, and 72, is exactly the same in construction as the lower plunger pump, having the same size of plunger, 18 inches diameter; it pumps the water from an independent supply entering at the point L, which is 217 feet down the shaft. This water is collected in an extensive standage in an upper seam of coal shown black in the sections, Figs. 7 and 8; and being comparatively pure, so as not to injure the condensing apparatus or boilers, the whole of

it is delivered into the condensing cistern, which is thereby kept at the temperature of 50°. It is then used for all the boilers at the lower part of the works, and also for the tuyeres at the blast furnaces. This water not being of a corrosive nature, cast iron clacks are used in the upper plunger pump, fitted exactly the same as the brass clacks already described in the two other pumps.

The pipes of the rising main of 19 inches internal diameter are cast in 9 feet lengths, as shown in Fig. 26, Plate 76, the thickness of metal varying from $1\frac{5}{8}$ inch at the bottom of the rising main to 1 inch at the top of the pit, as shown in Figs. 26 and 27. The joints of the pipes are flanged joints, as shown enlarged to one quarter full size in the section, Fig. 29, and the end of each pipe is recessed 1 inch into the end of the next; the bearing faces O O are faced in the lathe, and between them is inserted a flat turned wrought iron ring, $\frac{1}{4}$ inch thick, wrapped round with tarred flannel, as shown black in Fig. 29. This is found to make a perfectly water-tight joint, the tarred flannel becoming squeezed up into the spigot and socket joint when the bolts are screwed up, as shown in Fig. 29. There are eight $1\frac{1}{2}$ inch bolts to each joint, with a bracket $1\frac{1}{2}$ inch thick cast between each bolt hole, as shown in the plan, Fig. 28; and the thickness of the flanges is the same at all the joints, as shown in Figs. 26 and 27, whatever the thickness of metal of the pipes themselves. In the whole of the pipes also the full thickness of metal, $1\frac{5}{8}$ inch, is retained for a length of $7\frac{1}{2}$ inches from the joint, to the ends of the brackets, as shown in Figs. 27 and 29.

The main pump spears, shown in the general vertical sections, Figs. 7 and 8, Plates 70 and 71, are made of pitch pine, the several lengths fitted together with butt joints in the same manner as the spears of the bucket pump already described; the joints being secured with four heavy wrought iron strapping plates, two of which are 18 feet long and the other two 16 feet long, all of them 7 inches wide and 2 inches thick in the middle, tapering to 1 inch thick at each end. The main spears are 16 inches square at the top and 15 inches square at the bottom; the five top lengths are each exactly 45 feet long, and the bottom length 50 feet long.

These spears work through heavy cast iron guides M, Figs. 30 to 32, Plate 77, which are supported on oak buntings 9 inches square resting on a cross bunting 12 inches deep by 10 inches wide, the latter serving also as a stay for the pumps. The part of the main spears which works through the cast iron guides is covered with hard wood liners or sliding pieces N about $1\frac{1}{2}$ inch thick and planed up quite true and parallel, which may be easily replaced when worn. These spear guides are placed at the third, fourth, and sixth lengths of the spears, as seen in Figs. 7 and 8. There is no guide on the fifth length of spear, passing the upper plunger pump K, Figs. 7 and 8, as there is no room on the spear to place one there; but the two plunger pumps being fixed one on each side of the main spears are so nearly balanced that little or no vibration takes place at that point. The top spear leading from the end of the engine beam is guided by the banging beams P, Fig. 33, Plate 78, on the two sides only, the back and front being left open, Fig. 34, to allow of the vibration of the spears consequent upon the arc described by the extremity of the engine beam. The second spear from the top is guided all round by wood buntings and liners fixed on the spears, as shown at Q in Figs. 7 and 8, and to a larger scale in Figs. 35 and 36, Plate 78; the front liner being made hollow and the back one convex, Fig. 36, to allow of the proper amount of vibration of the spears, which is about $3\frac{1}{2}$ inches at that point, as shown by the dotted centre lines in Fig. 36. In this view the spear is shown in the extreme position of vibration on one side of the vertical, being then at the bottom of its stroke.

There are two banging pieces R R, Figs. 33 and 34, Plate 78, clamped and bolted on each side of the main spears at the pit top, working down upon heavy oak buntings; and also two cast iron banging pieces S S, Figs. 30 and 31, Plate 77, about 130 feet down the shaft, which is as low as they can be placed. These are fixed by 2 inch bolts on the sides of the main spear, and work down upon two oak buntings 16 inches square, which rest at one end for about $2\frac{1}{2}$ feet length in the shaft side, and at their outer ends on another oak bunting in front of the main spears, 4 feet 11 inches deep and 14 inches thick, going fully 3 feet into the shaft side at each

end. These buntings with those at the top of the shaft form a secure resting place for the main spears when the engine is out of the house; and it is hoped they would be strong enough to stop the fall of the spears in case one of the clacks should ever break or any part of the pumps or rising main should burst. Figs. 30 to 34 show the spears at the bottom of the stroke, with the banging pieces R and S just clear of the banging beams. In ordinary working the equilibrium valve of the engine is shut at such a point that the banging pieces on the spears never touch the banging beams. The rising mains I of the pumps are stayed at every third pipe by wrought iron straps passing round the pipe and screwed through the buntings, as shown in Figs. 35 and 36, Plate 78, so that should a pipe require changing it would not be necessary to remove a single bunting; and the buntings are fixed so firmly in the shaft side that it would be rather a serious matter to remove one.

In Figs. 7, 8, and 11, Plates 70 to 72, is shown the recess U made in the shaft side for the purpose of packing and examining the glands of the plunger pumps F and K, so that the man may be entirely out of danger in the shaft. In Fig. 9 there is a recess for the suction pipe of the upper plunger pump K to pass through to the well L, and in Fig. 10 a similar recess to the well E for the suction pipe of the lower plunger pump F; the suction pipe is scaffolded over, and forms a platform to stand upon out of the shaft for changing and examining the clacks, thus keeping the shaft quite clear for repairs when needed.

In the rising main of each of the plunger pumps is placed a 2 inch valve with a pipe leading back to the well from which the pump draws, for the purpose of regulating the supply of water to each pump. These valves are worked by rods from the surface, and there are three floats, one in each of the plunger pump wells and the third in the well S at the bottom of the shaft, Figs. 7 and 8, Plates 70 and 71. The tops of the float rods are in sight of the engineman, so that by means of the return valves part of the water can be allowed to run back into either of the plunger pump wells, in order to keep the water level always above the top of the windbore, whereby the pumps are kept fully supplied with water, and always,

as it is termed, "working on the solid." From each of the plunger pump wells an overflow pipe V, Figs. 7 and 8, is taken, one 6 inches and the other 8 inches bore, to allow any irregularity of supply to run to the bottom of the shaft.

As the engine is single-acting, the moving pit work has to be heavy enough to balance not only the column of water in each of the two plunger pumps, but also the piston, parallel motion, plug rods, and all the work hanging on the beam inside the engine house. The moving pit work &c. on the outer end of the beam weighs a little more than 34 tons, and the weight of the two columns of water is about 24 tons, leaving a balance of more than 10 tons in excess upon the outer end of the beam to overcome the weight of the piston and the work on the inner end of the beam, which amounts to rather more than 7 tons, thereby leaving an excess of weight of about 3 tons to overcome the friction of the pit work, and to give the necessary speed of motion to the water in the rising mains.

This engine has purposely been made larger than is necessary for the present requirements of the colliery, in order to allow for considerable future extension of the workings without the need of again increasing the engine power for drainage. In consequence of the engine being thus too large at present for the work to be done, it does not yet admit of expansion being carried to any high degree; for the total mass set in motion by the engine amounts at present to only about 54 tons, taking the effective inertia of the beam as equal to 6 tons collected at the extremities; which is not sufficient to control the velocity of the stroke at starting within the limits that are safe for the pump work, unless the degree of expansion be very limited, so as to allow of a comparatively low initial pressure of steam.

The accompanying indicator diagrams, Figs. 37 to 40, Plate 79, show the working of the engine under different degrees of expansion. Fig. 37 shows the diagram obtained in an experiment in which the steam was cut off at 71 per cent. of the stroke, which is about the limit of expansion considered prudent for experiment, on

account of the risk of damage to the pit work from the concussion produced at the beginning of each steam stroke by the sudden snatch of the engine upon the pump rods. Fig. 38 shows a lower degree of expansion, with the steam cut off at 82 per cent. of the stroke; and Fig. 39 shows the diagram obtained when the steam is cut off at 84 per cent. of the stroke, and Fig. 40 at 91 per cent., which is about the range of expansion used in regular working. The boiler pressure was 14 lbs. per square inch above the atmosphere, but throttled down to about 8 lbs. on admission to the cylinder. The boilers are not at present roofed over nor covered at the top, nor are the steam pipes from them coated in any way; and the construction of the boilers, plain egg-ended boilers with the flue underneath divided by a middle wall, giving only one return of the heat under the boiler, is not adapted for an economical consumption of fuel; the evaporative duty obtained is consequently only about 3½ to 4 lbs. of water per lb. of coal slack. Under these circumstances the duty at present attained by the engine amounts to only about 27 million lbs. raised 1 foot high by the consumption of 1 cwt. of slack.

Each of the two pumps delivers about 108 or 110 gallons of water at each stroke, according to the length of stroke allowed to the engine. The number of strokes the engine is making at the present time is 4 per minute for twelve hours, delivering about 52,000 gallons per hour, and the engine standing the other twelve hours. It has worked up to 7 or 8 strokes per minute for a very short time, and as slow as ¾ stroke per minute. The quantity of water in the colliery fluctuates a great deal, requiring a corresponding variation in the rate of working the engine: during the past summer about 1½ strokes per minute during the twelve hours cleared the colliery of water; but now it requires about 4 strokes per minute to drain the workings in the same time.

The CHAIRMAN observed that the paper now read contained a great deal of practical information, and gave very ample details of the construction and working of the large pumping engine. The adoption of the wrought iron engine beam was a feature of particular interest after the terrible accident that had occurred at the Hartley Colliery by the breaking of the large cast iron beam. In the wrought iron beam described in the paper the two massive slabs composing it were of such dimensions that it would not have been thought practicable a few years earlier to produce them at any ironworks. Now however that this had been so successfully accomplished in the Clay Cross beam, it would probably lead to the introduction of similar large wrought iron beams wherever there were any great strains to be borne, in order to prevent any risk of the recurrence of such a terrible catastrophe as that at Hartley.

Mr. F. J. BRAMWELL observed that in reference to the reasons for adopting the Cornish pumping engine for draining the colliery at Clay Cross, in preference to a rotary pumping engine, it had been mentioned that with the latter, if the pump should ever be only half filled with water from any defect of the valves, the plunger meeting the water at half stroke would produce a concussion so violent as to risk breaking some of the machinery. But he thought the same objection applied equally to the Cornish engine, as he did not see what there was to restrain the violence of the concussion except the water itself in the pump barrel. He enquired whether there was any special self-acting arrangement in connexion with the equilibrium valve for partially closing the valve and wiredrawing the steam in the event of the plunger missing its stroke or the first portion of its stroke.

Mr. HOWE replied that there was no arrangement for closing the equilibrium valve in case of the engine ever going out of doors at an excessive speed; but the valve itself was of small area, and would thereby have some effect in checking though not entirely preventing too rapid an outdoor stroke. In crank pumping engines he had seen many serious breakages of the machinery in consequence of the plunger missing the first part of its stroke and then suddenly meeting the water in the pump; and in such engines the danger of

injury from the concussion was heightened by the circumstance that the force of the concussion arose not merely from the momentum of the moving parts, but was further increased by the engine power, in consequence of the steam continuing to act in the cylinders, so that the plunger was driven down upon the water by the full power of the engine. In the Cornish engine on the other hand, while the concussion was no doubt equally severe as far as it arose from the momentum of the plunger and pump rods, it was not further augmented by any engine power, as the pump rods made the down stroke by their own weight alone, without any aid from the steam. Moreover as the liability of a valve to stick once during any period of time was in proportion to the number of times it had to open and shut in that time, there would be greater risk of such concussions in the pumps with a rotary pumping engine running quick than with a large Cornish engine making a smaller number of strokes.

Mr. F. J. Bramwell concurred in the greater risk of a valve sticking in a large number of short strokes as compared with a few long strokes, since of course the oftener it had to open, the greater was the risk of its sticking. But in other respects he did not see that the Cornish engine possessed the advantage which had been attributed to it over a rotary engine with crank and flywheel, and thought on the contrary the advantage was on the other side. In the Cornish engine there was certainly nothing else beyond the momentum of the pump rods and plunger to produce a concussion when the plunger met the water at half stroke; but then, in consequence of the massiveness and weight of those parts in a Cornish engine, their momentum was far in excess of that in a crank engine: and though in the latter engine the steam was continuing to exert its force in the cylinder during the stroke of the pump, yet the addition of the heavy flywheel completely controlled the speed of the engine, and prevented it from running off instantly if ever the pump missed the beginning of its stroke; whereas in the Cornish engine, as soon as the equilibrium valve was once opened, the engine immediately went off unrestrained in the outdoor stroke, without any provision for checking its motion in the event of an accident. He therefore thought the concussion produced by such

an accident would be far greater in the Cornish engine than in a rotary pumping engine with crank and flywheel.

Mr. E. A. Cowper enquired what was the reason why double-beat valves were not employed in place of the clack valves in the pumps of the engine described in the paper. Double-beat valves were used he observed for the steam cylinder, and they were almost universally adopted in Cornish engines where it was desired to work the steam to a good degree of expansion.

Mr. Howe replied that the clack valves in the pumps had been adopted because they were so simple in construction, and because there were not such skilled mechanics to be had at collieries as at waterworks for keeping the valves of the pump work in order. The simple clack valves in the pumps had been found to work remarkably well, and stood the work well, as they had not been looked at now for $\frac{3}{4}$ year since the pumps were first started. The concussion produced by the valve lids closing was very slight, and scarcely perceptible except when the engine was worked at a high speed; it was most apparent at the end of the indoor stroke of the engine, when the suction valves in the pumps were closing previous to the down stroke of the plunger.

Mr. E. A. Cowper observed that such valves were certainly not suitable for any high speed of working, on account of the violent concussion they would then produce in closing; but in the engine now described the degree of expansion of the steam was so limited that he thought it could scarcely be regarded as a Cornish engine, but rather as an example of the early Boulton and Watt style of engine. In the present instance however there was probably no particular need for economy in the consumption of coal; and this seemed to be the case from the boilers being of the plain cylindrical form, instead of Cornish boilers with an internal flue.

Mr. J. Fernie believed the single-beat pump valves were generally adopted for collieries on account of the dirty water to be pumped, while the double-beat valves were confined to waterworks where the water was clear.

Mr. J. R. Warham said that was the case, and no doubt the double-beat valves were the best; but in collieries there was so

much dirt and sand mixed with the water in the process of sinking, all of which had to pass through the pump valves, that double-beat valves would involve too much trouble and expense in keeping them in working order.

Mr. E. A. Cowper enquired whether a sufficient degree of vacuum was obtained in the condenser in regular work; he thought the vacuum would be produced more quickly and efficiently if the injection water were admitted in a thinner stream and more divided form, by means of a conical injection valve throwing a thin conical sheet of water violently against the sides of the condenser, so as to present a greater extent of cooling surface for condensing the steam rapidly.

Mr. Howe replied that at the usual working speed of not more than four strokes per minute the vacuum in the condenser was $13\frac{1}{2}$ lbs.; but in running at a higher speed, about five strokes per minute, the injection was found rather deficient, and had therefore subsequently been increased. The injection opening was so placed as to throw the water against the opposite side of the condenser, in order to make the water splash and expose a greater surface to the steam.

The Chairman asked what had been the extra cost of the wrought iron engine beam as compared with a cast iron beam of the same size.

Mr. Howe replied that at the time of originally designing the engine it was intended to have a cast iron beam, but just then the Hartley accident occurred, and it was therefore determined to adopt a wrought iron beam; and the extra cost of the present wrought iron beam had been £480 above that of a cast iron beam for the same engine.

Mr. J. Fernie had had an opportunity of seeing the engine at work at Clay Cross Colliery, and had been greatly pleased with the excellent workmanship and ample strength of all its parts and the substantial nature of the pump gear. The great feature was certainly the large wrought iron beam, made of two very strong wrought iron slabs rolled solid throughout their entire length of 36 feet, and 7 feet wide in the centre. There had been other designs also

for wrought iron engine beams since the Hartley accident, and he understood a large wrought iron beam was now being made at Wednesbury of thin plates rivetted together.

The CHAIRMAN said the wrought iron beam in process of construction at his own works at Wednesbury was being made of a number of plates rivetted together, simply as a cheaper mode of construction than the use of solid-rolled massive slabs of the large size required. The rivetted beam would of course not be so solid and not quite so strong for the same thickness as the solid-rolled beam at Clay Cross; but its strength might be made up to the required amount by adding a sufficient number of thicknesses of plates. The total length of the rivetted beam was 28 feet, and the depth in the centre 4 feet; it was composed of two slabs, each made up of three plates of $\frac{3}{4}$ inch thickness rivetted together, making a total thickness of $2\frac{1}{4}$ inches for each slab. He enquired what had been the total cost of the Clay Cross pumping engine without the boilers or pumps.

Mr. HOWE replied the total cost of the engine alone, including the wrought iron beam, but without the boilers, engine house, or pumps, was £3130; and including the boilers, engine house, and chimney, the total cost was under £5000. The pumps and pump rods cost about £2500 extra.

The CHAIRMAN asked how the joints of the rising main in the pumps were found to stand in work; and what means was provided for descending the pump shaft to examine the valves and pack the glands.

Mr. HOWE replied that he had found the whole of the joints of the rising main stood perfectly water-tight in work; the construction of the joints was very simple, having merely the turned wrought iron ring wrapped round with tarred flannel inserted between the turned bearing faces of the joint. For examining the valves and packing the glands a small separate winding engine was provided, for ascending and descending the shaft by means of a bucket, independent of the pumping engine.

Mr. J. FERNIE exhibited a new construction of indicator of American invention (Richards'), with which he had takèn the

diagrams from the Clay Cross engine. It had a much shorter stroke than the ordinary indicator, with a proportionately stronger spring, and the motion was multiplied by the long arm of a very light lever carrying the pencil, which was made to move in a straight line by means of a light parallel motion; the movement of the pencil was more steady and free from jumping, in consequence of the diminution of speed of piston from the shortness of stroke and the greater strength of the spring, and the figures obtained showed a very clear and steady line.

Mr. E. A. Cowper had no doubt such an indicator would work steadily; he had many years ago designed such a one, and Mr. Gooch made one on the same principle, with which steady diagrams had been obtained from locomotives on the Great Western Railway running up to a speed of more than 60 miles an hour.

Mr. F. W. Webb said he had used the Richards' indicator for taking diagrams from the "Lady of the Lake" outside cylinder express locomotive on the London and North Western Railway, the engine shown in the International Exhibition of 1862; and the diagrams obtained with it were perfectly steady up to 65 miles an hour. By having a second barrel for the paper, so as to change the paper quickly, as many as three dozen diagrams had been taken with the indicator from that engine in 40 minutes time, in running the 25 miles from Crewe to Stafford.

The Chairman proposed a vote of thanks to Mr. Howe for his paper, which was passed.

The following paper was then read:—

ON THE PROCESSES AND MECHANICAL APPLIANCES IN THE MANUFACTURE OF POLISHED SHEET GLASS.

By Mr. RICHARD PILKINGTON, Jun., of St. Helen's.

The manufacture of British Sheet Glass was introduced into England abont the year 1832 by Messrs. Chance Brothers of Birmingham. Since then it has become generally used, having almost superseded crown glass, in consequence of the comparative ease of obtaining the large squares at present required for windows, and the absence of wave lines by which the vision is so much distorted in crown glass. The average size of sheet glass is 40 inches by 30 inches, but if required it can be made much larger; whilst with crown glass it is almost impossible to procure a square as large as 34 inches by 22 inches. Sheet glass when used for windows has generally a peculiar appearance when viewed from the outside of a building, on account of the unevenness of its surface, an eyesore partially obviated by the improved method of flattening, but entirely removed when the glass is polished. When polished it is known by the name of patent plate, to distinguish it from British plate. This polished sheet plate has a decided preference over British plate, being harder and more difficult to scratch, besides taking a higher polish; it is also cheaper.

The manufacture of polished sheet glass consists of the three following processes:—1st, melting and blowing; 2nd, flattening; and 3rd, polishing.

1. *Melting and Blowing.*—Two furnaces are required, one for melting the materials or "frit," and the other for reheating the metal whilst blowing it into a cylindrical form. The melting furnace is a reverberatory furnace, arranged for maintaining a high temperature with great uniformity and freedom from dust or other impurities arising from the fuel. The furnace, an eight-pot one, is

shown in Figs. 1 and 2, Plate 80. There are four "gathering holes" or "working holes" A A on each side of the furnace, as shown in the side elevation Fig. 2, each of the eight pots B having a working hole. The temporary brickwork C beneath each working hole can be removed when required, either to turn a pot or whilst fixing a new one. A raised bed D extends the entire length of the furnace, upon which the pots are placed on each side of the firegrate. The firegrate E extends the entire length of the furnace, with the exception of a space of about 4 feet length, and is fed from each end of the furnace. The air is supplied through the underground passage F entering from the open air; and by means of closely fitting doors the draught is regulated with great nicety.

Formerly it was considered necessary to use stone for the melting furnaces, but at the present time large bricks made of best fireclay have a decided preference. These firebricks vary in weight from a few lbs. to several cwts.; they are all made in moulds, dried, partially burnt, accurately dressed to templates, and built into the furnace, the whole being firmly secured by cast and wrought iron binders, as shown in Figs. 1 and 2, Plate 80. A small fire is lighted upon the firegrate and gradually increased, first to dry the furnace and afterwards to bake it: great care and attention are given to this operation, for upon it depends the duration of the furnace. After being baked, the furnace receives its number of pots, generally four or five on each side of the firegrate, in all eight or ten pots.

The manufacture of these pots is a matter of special importance, and they are made of the very best Stourbridge fireclay, which when thoroughly tempered is formed into rolls of about 1 lb. weight each, and worked layer upon layer into a solid mass, free from cavities containing air, and making a pot of about 4 feet height inside, 5 feet diameter at top and about $4\frac{1}{2}$ feet diameter at bottom inside, weighing when dried about 25 cwts., and containing about 22 cwts. of melted metal. Great care is requisite to prevent any particles of foreign matter or dirt from getting into the clay; for if that were to happen the pot would not last its time, but would most likely give way when first heated to the working temperature. The average duration of a pot is about eight weeks, and their estimated

value about £9 each. After being made, a pot remains in the same room for a year, the temperature being maintained at 60° Fahr., and it is then removed to a warmer room, where it remains in a temperature of 90° until it is wanted. When required for use it is taken to the "pot arch" to be baked, where the heat is gradually increased to that of the melting furnace, to which it is conveyed whilst red-hot as quickly as possible by means of a carriage or a crowbar on wheels, and placed on one side of the firegrate: this operation is repeated until all the pots are fixed in the melting furnace. The furnace ends are now closed, with the exception of the firehole at each end. A small portion of "cullet" or broken glass is put into each pot, and when melted is ladled so as to run down over the interior surface of each pot, after which the heat is increased for a short time. The pots are thereby glazed and are now ready to receive the material to be melted.

The quantity of raw material or "frit" allotted to each pot is filled into it in three or four charges, allowing a sufficient interval of time to elapse between each charge to ensure the previous one being melted. About sixteen hours of intense heat are required to melt the entire quantity, during which time the fluid metal boils violently, and before it can be worked requires cooling, which takes about eight hours. Whilst cooling, the small bubbles of air arising from the boiling of the metal ascend and pass away, leaving the metal clear, excepting the surface which is coated with impurities from the frit, from the roof of the furnace, and from the dust of the fuel, all of which must be removed before commencing work. Inside each pot and floating upon the surface of the metal is an annular ring made of fireclay 2 inches thick, having an internal diameter of 18 inches; this inner space of 18 inches diameter is cleaned, instead of the entire surface of the metal, thereby saving both time and material. The cleaning or skimming is performed by means of a light iron rod, chisel pointed, which being warmed the metal adheres to it; and this process is repeated whenever any impurities are perceived upon the surface of the metal.

The surface of the melted metal being cleaned, the workman dips into it the blow-pipe, Fig. 3, Plate 81, having previously

warmed the nose end of the pipe. Withdrawing 2 or 3 lbs. of the metal, he allows it to cool to a dull red, and then dips the pipe again; collecting by degrees in this way, as shown in Fig. 4, a sufficient quantity to produce a given sized sheet of glass, which on the average would weigh about 20 lbs. Then while cooling the pipe he continually turns it round, drawing it towards himself, and in so doing forces the metal beyond the nose end of the pipe by means of the forked rest in which the pipe revolves, as shown in Fig. 5, leaving as little metal as possible upon the pipe. The blower now takes the pipe and places the red-hot mass in a hollowed wooden block upon the ground, Fig. 6, keeping the pipe in a horizontal position whilst revolving it, thereby producing a solid cylindrical mass of metal. During this process his assistant allows a fine stream of cold water to run into the block from a sponge, keeping the wood from being burnt and giving a brilliant surface to the glass. He next raises the pipe to an angle of about 75°, and blows until he has produced a hollow pear-shaped mass, Fig. 7, with its largest diameter the same as that of the finished cylinder. During this operation his assistant keeps the block wet, and a second block is generally used when commencing the blowing.

The glass now requires reheating, which is done at a furnace built of ordinary brickwork in an oblong form, its dimensions being determined by the number of blowers intended to work at it, generally four five or six at each side. The ground at each side of this furnace is excavated to a depth of about 7 feet, a width of about 16 feet, and the same length as the furnace; and over each of these spaces four five or six wooden stages are erected at distances of about 2 feet apart. Having reheated the glass, the blower repeatedly blows to maintain the cylinder of equal diameter throughout, whilst lengthening it by swinging it backwards and forwards in the 2 feet space, and occasionally swinging it round over his head; until a cylindrical piece of glass is produced, Fig. 8, about 11 inches diameter and about 50 inches long, closed at one end and having the blow-pipe attached to the other end. The blower first opens the closed end as follows: enclosing as much air as possible within the cylinder, and stopping the

mouth-piece of the pipe with his hand, he exposes the end of the cylinder to the heat of the furnace, which whilst softening the glass at the end expands the contained air to such an extent that a small hole is burst in the glass, as in Fig. 9, Plate 82. This hole is flashed open by revolving the pipe quickly, and when flashed the end of the cylinder is withdrawn out of the furnace; and by keeping the pipe in a vertical position for a few seconds the metal cools sufficiently to keep its shape. The cylinder is then placed upon a wooden trestle, and by touching with a piece of cold iron the pear-shaped neck near the pipe nose at G in Fig. 9 a crack is formed, which is continued round the neck by gently striking the blow-pipe, and thus the pipe is released, as seen in Fig. 10.

The cylinder has now one end of full diameter, but the other is contracted to about 3 inches diameter, Fig. 10, Plate 82, and must therefore be cut off. This is accomplished as follows: the cylinder having become cold whilst remaining on the trestle, the workman collects a small portion of metal upon the end of an iron rod and draws it into a thread of glass about $\frac{1}{8}$ inch diameter by means of a pair of pinchers. This thread he passes round the body of the cylinder at H H in Fig. 10, and after it has remained on a few moments the pinchers dipped in cold water are applied to the heated part, and the sudden contraction causes the end to fly off with a sharp report, leaving the cylinder about 45 inches long and 11 inches diameter.

2. *Flattening.*—To produce a flat sheet of glass from the cylinder thus obtained forms the second process of the manufacture. The flattening is acomplished as follows. The end of the cylinder that was flashed being slightly contracted in diameter and the thickness of metal much reduced, it is first necessary to cut off about 2 inches length from that end: for this purpose the cylinder is supported in a vertical position by means of a cradle, as shown in Fig. 11, Plate 82, over a small horizontal table; the bottom edge of the cylinder is introduced between the jaws of the small cutting instrument I, and the moveable jaw carrying the cutting diamond is pressed by a spring against the interior surface of the cylinder;

then by gently pushing the instrument forwards round the cylinder, allowing it to run freely upon its wheels, the end of the cylinder is cut off perfectly true. The cylinder then requires splitting longitudinally, which is accomplished by placing it in a horizontal position in a wooden cradle, as shown in Fig. 12, and a diamond fixed in the cleft of a stick at J is drawn along inside the cylinder from end to end, guided by the straight edge K, a gentle pressure being exerted on the glass in opposite directions at the diamond cut to complete the splitting.

The cylinder is now taken to the flattening kiln, Fig. 13, Plate 83, which consists of two furnaces built together, the first L for flattening, and the other M for annealing, the former being maintained at a much higher temperature than the latter. A portion of the bottom of the flattening kiln L, slightly larger than the largest sheet of glass to be flattened, is supported upon a carriage N, which with the flattened sheet is made to travel into the annealing kiln M, this plan being a very great improvement over the old method of pushing the flattened sheet whilst in a soft state. The moveable bed N is either of clay or stone, and by careful work is made as true as possible; upon this a sheet of glass is first flattened and left there to flatten others upon, in order to obtain sheet glass with as true a surface as possible. The split cylinder to be flattened is gradually introduced into the flattening kiln, being placed first at O and then at P, and when sufficiently warmed is placed upon the glass bed N with its split side uppermost; the heat soon softens it, so that with a slight assistance from the workman it lies down nearly flat on the bed N, and the sheet is afterwards carefully rubbed as flat as possible with a piece of wood fixed to the end of an iron rod. The moveable bed N is now pushed forwards into the annealing kiln M, as shown by the dotted lines, and after placing another cylinder to warm at O and P the workman removes the flattened sheet from the carriage N by means of a tool like a fork, and places it upon a prepared part of the floor of the annealing kiln M, to stiffen previous to piling it. The carriage N is now returned to the flattening kiln L, and the flattening operation repeated till the carriage again appears in the annealing kiln M.

The previously flattened sheet is first piled on its end against one side of the kiln at R, and then the last flattened sheet is removed off the carriage N, and left to cool on the floor of the annealing kiln like the previous sheet. This flattening process is continued until the annealing kiln M is filled, when it is closed up and allowed to cool, generally from 24 to 36 hours, the time being regulated by the thickness of the glass. On the completion of the cooling, the kiln M is opened and the sheets of glass are taken to the warehouse, where they are sorted to suit various purposes, a very large portion being packed and sent away without undergoing any further process.

3. *Polishing.*—The sheets intended to be polished are now selected, and pass through the third process of the manufacture to produce Polished Sheet Plate. Two processes are necessary for this purpose, smoothing and polishing.

Smoothing consists in working two sheets of glass one upon the other by hand with emery and water between them, and as their surfaces become obscured finer and finer emery is used until the surfaces are smoothed free from all defects. The apparatus used consists of a wooden bench, one half of which is 6 inches higher than the other; upon the former is placed a slab of slate about $1\frac{1}{2}$ inch thick, larger than the sheet of glass, having as true a surface as possible. Upon this slab a sheet of glass is laid, with a piece of wet calico between the surfaces of the glass and the slab; by exerting a gentle pressure upon the glass the air is expelled from between them, and the sheet of glass is consequently held down upon the slab by the whole atmospheric pressure upon its surface, which holds it so firmly that when the sheets have to be raised from the slab many are broken even by experienced workmen. The wet calico is used in this case instead of plaster of paris for bedding the sheet of glass upon the table. In consequence of the close adhesion caused by the atmospheric pressure when the surfaces of the two sheets of glass get so true as to become closely in contact, it is impossible to work two large sheets one upon the other with the finest emeries, and it therefore becomes necessary to perform the latter portion of the rubbing

process with a small piece of glass, say about 10 inches by 5 inches, until the process is completed. Both sides of the sheet of glass having been smoothed in this manner, and after a careful examination found free from defect, the sheet is then handed over to the polishing machine.

The perfection of the smoothing process in entirely dependent upon the purity of the emery, and the perfect uniformity of the grain in each successive quality employed; and consequently a very perfect process of cleansing and sorting the emery is requisite. The ordinary ground emery contains, besides numerous degrees of fineness of grain, many impurities which must be removed, and the good emery must also be accurately sorted into portions varying in size of grain from coarse to the finest. For every degree of fineness a separating vessel or cylinder is required; and taking No. 1 as the coarsest quality, that cylinder is made the smallest in the series, No. 2 cylinder about twice the capacity of No. 1, and No. 3 twice the capacity of No. 2, and so on throughout the required number of cylinders. The emery sorting apparatus is shown in Fig. 14, Plate 83, and consists of the required number of cylinders fixed so that No. 1 cylinder is about 3 inches higher than No. 2, and No. 2 the same height above No. 3, and so on. The cylinders are made of copper, and inside each is fixed a copper funnel S, long enough to reach within 3 or 4 inches of the bottom of the cylinder; and in the bottom of the cylinder is a hole closed by a wooden plug or a valve T of about 3 or 4 inches diameter, which is held up by the rod and spring balance U. The action of the apparatus is as follows. A supply of water being maintained by the cistern V, a constant stream is delivered by means of the tap W into the funnel of No. 1 cylinder; the water descends through this funnel to the bottom and ascends through the annular space to the top of the cylinder, whence it is conveyed by the spout X and poured down the funnel of No. 2 cylinder, ascending in the annular space of No. 2 and passing by the spout to No. 3 funnel; this is repeated as often as there are cylinders, and from the last and largest cylinder the overflow is carried to a drain. When the stream of water is running through all the cylinders and also passing away at the

overflow, the powdered emery to be cleansed and sorted is sprinkled into the funnel of No. 1 cylinder, and this is continued until enough has been fed to fill up to within $\frac{1}{2}$ inch of the bottom of the funnel: No. 1 being the smallest cylinder, the current of water through it will be the fastest, and the grains of emery left behind in this cylinder will consequently be the coarsest. The feeding of the emery is then stopped for a short time, and the stream allowed to continue until the water is running quite clear into the funnel of No. 2 cylinder: the valve T at the bottom of No. 1 cylinder is now opened, allowing the emery and water to fall into a vessel placed beneath to receive it; and as soon as the stream of water is again running through all the cylinders and passing away at the overflow, more emery is again sprinkled into No. 1 funnel. The succeeding cylinders are emptied in the same way, as they respectively become filled with the finer sorts of emery. The beauty of this process is the simplicity of apparatus required and the certainty of always obtaining an exact repetition of the several degrees of fineness in the respective cylinders. It will be observed that, in consequence of the cylinders increasing successively in capacity, the current of water ascending in the annular spaces decreases in velocity in the same proportion: consequently the emery deposited in each successive cylinder increases in fineness over that deposited in the previous one.

For the final process of polishing the sheets of glass after smoothing, the machine used is the same as that described at a previous meeting for polishing plate glass, (see Proceedings Inst. M. E., 1863, page 213, and Figs. 4 and 5, Plate 59.) The polishing benches have two bars carrying the polishing blocks and working lengthways backwards and forwards over the table on which the sheet of glass is laid, which is made to travel alternately from side to side transversely to the bars. The polishing blocks are worked at about sixty double strokes per minute, and the bars carrying them are supported upon rollers at a height of 6 or 8 inches above the table. The moving table is worked similarly to the table of a planing machine, moving one way quicker than the other by a reversing motion similar to that of a planing machine bed. It is generally considered

that to obtain a good polished surface the polishing blocks should not pass twice in succession over the same surface. Upon the moving table are fastened slabs made of a wooden frame covered with slates, upon which the sheets of glass to be polished are bedded in plaster of paris. After one side has been polished, the glass is taken up and relaid, and the other side polished. The polishing blocks are about 5 inches square, covered with felt and weighted with about 84 lbs. each. The red liquor used in polishing is red oxide of iron, obtained by burning sulphate of iron in a reverberatory furnace to a dark red when cold, and it is then ground in water to the finest grain possible. The cutting grain of this material is about the hardest and finest that can be produced, and well worth examination by the microscope.

Mr. Pilkington exhibited a series of specimens from the St. Helen's Crown Sheet and Plate Glass Works, illustrating the several stages of the manufacture and the materials employed.

The Chairman observed that the members had had an opportunity on the occasion of the Liverpool Meeting of seeing the manufacture of plate glass at the Ravenhead Works, and a paper on the subject had been read on that occasion; and the present paper gave a corresponding description of the manufacture of polished sheet glass.

Mr. P. Rigby observed that polished sheet glass was a very superior article to the crown glass of which it had taken the place, and required more care in the final polishing process in order to get both sides of the glass finished to the same degree of polish. Much depended upon the correct separation of the emery powder into proper gradations of fineness, which was effected by the successive cylinders in the emery washing apparatus being made in correctly adjusted progression as regarded their size. Great care was also needed in feeding the emery powder into the first funnel, so as not to go on feeding too long, otherwise some of the coarser particles would get carried over by the current of water into the next cylinder along with the finer sorts. The time of polishing the sheets of glass

was generally required, in his own experience at Messrs. Chance's works, to be longer for the side first polished, because when the plate was turned over for polishing the second side, the first surface became slightly dulled by being laid in the plaster; and he enquired whether in the specimens exhibited of polished glass the time of polishing had been equal for both sides or longer for the first side.

Mr. Pilkington replied that it took about nine hours on an average to polish each side of a sheet of glass, but there was no fixed time for the process, the polishing being continued until the surface of the glass was brought up to the requisite brightness; and he had not found that it afterwards became dulled at all by being laid in plaster for polishing the other side, the plaster having no sensible effect on the brightness of the surface. Even in what was called the rough state however, before smoothing or polishing, sheet glass was quite equal in appearance to ordinary crown glass; while the finest and thinnest sort of polished glass, of which a sample was shown, was that made for the use of photographers and for framing fine engravings. The emery sorting apparatus was found in practice to divide the different sizes of emery with extreme accuracy into the respective cylinders, as was proved by examining with a microscope the several degrees of fineness.

Mr. J. E. Clift enquired whether the rubbers had to be removed at intervals during the polishing process, in order to examine the surface of the glass.

Mr. Pilkington replied that was not necessary, as the rubbers travelled far enough at each stroke to expose the whole surface to view, and the workman examined the degree of polish of the surface by holding a lighted candle near it while the glass was still lying on the slab of the machine. The process was stopped as soon as the glass appeared sufficiently polished.

Mr. F. J. Bramwell observed that if it were the fact that the surface of the glass became at all dulled by being laid in plaster, and if it were attempted to compensate for this by polishing the first side longer than the second, the result must be that both sides would be defective in polishing, the second side not being finished to a greater degree of polish than the first side would have after

lying in the plaster. The smoothing and polishing processes here employed were indeed identical with those in the manufacture of plate glass; but the latter required a preliminary process of grinding, on account of the unevenness of its surface on leaving the annealing oven, whereas the blown sheet glass had its surface sufficiently even to allow of its being laid at once on the smoothing machine without having undergone grinding. The emery sorting apparatus was the same that was used in plate glass machinery, and he did not think a more perfect plan could be devised for separating the several degrees of fineness; the principle was the simplest possible, the different sized particles being accurately sorted according to the velocity of the current of water in the successive cylinders, just in the same manner as a river discharging itself into a lake deposited the heavier portions of its detritus at the entrance and carried the lighter matters further out into the body of the lake. A similar method had formerly been employed in the preparation of beaver for the manufacture of hats, the hairs being separated from the beaver by a current of wind just sufficient to float the beaver; this accordingly deposited the hairs at a near point but carried the beaver to a greater distance. In grinding the emery the old plan had been to grind it dry under edge runners, and as there was no provision for removing the particles as fast as they were ground, the consequence had been that some portions were over-ground and impeded the grinding action of the machine upon the portions that still required grinding: now however by grinding the emery wet, with a stream of water constantly carrying off the particles as soon as they were ground, the machine was kept continually cleared and was enabled to grind in two days as much emery as it had previously ground in six. The principle of the stream of water was the same as that of the air blast used in millstones to remove the flour from between them, and in the American rice-husking machines for blowing away the husk of the rice grains as soon as it was broken up fine enough to be so removed.

The Chairman enquired whether any improved mode of laying and lifting the plates of glass on the machines had been devised, in order to diminish the risk of breaking the glass; he thought there

seemed room for improvement in that respect, for at present the loss by breakage of the glass in handling was very great.

Mr. Pilkington was not aware of any improvement having been made in that respect, though it was certainly much needed.

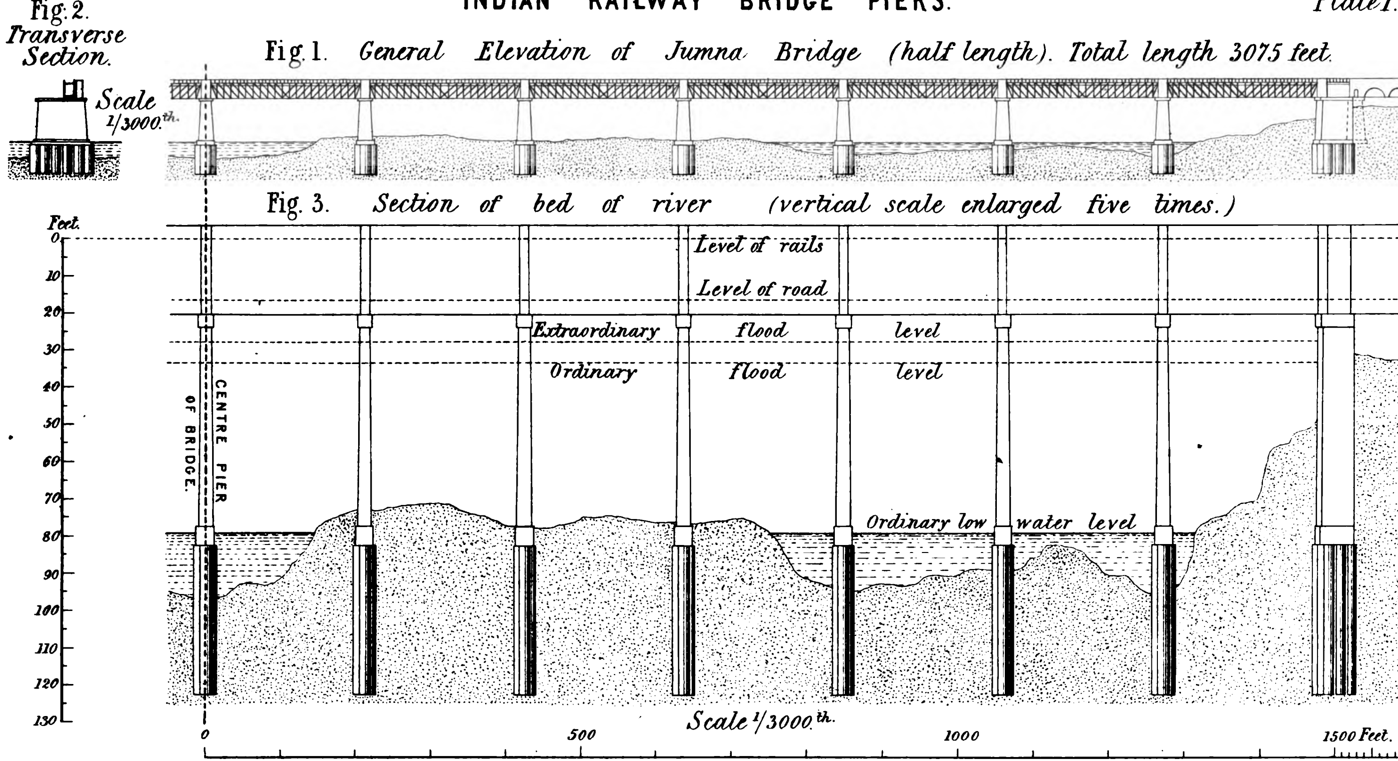
Mr. E. A. Cowper observed that for smoothing the sheets of glass, instead of the process being performed by hand as described in the paper, a machine was employed at Messrs. Chance's works, in which the smoothing action was produced by a link motion like the parallel motion of beam engines, the upper sheet of glass not working right round upon the lower, but passing over it in a curvilinear course with a figure of 8 movement. The melting furnace shown in the drawing appeared to be the ordinary form of furnace used for glass melting, previous to the introduction of Mr. Siemens' regenerative gas furnace. In the construction of the old furnace one practical difficulty arose from the "tears" or droppings of dirt from the brickwork forming the roof of the furnace, which dropped into the glass melting pots and damaged the glass; this was now obviated by setting the lower rows of bricks each a little in advance of the upper, so as to present a slight step inside the furnace, which prevented the "tears" from dropping and caused them to run down the sides of the furnace instead. The use of a current of air for separating fine substances, to which reference had been made, was also adopted in the process of grinding sulphur for vulcanising purposes, the sulphur being ground down to the condition of an impalpable powder which was carried away by the air into a proper receptable.

Mr. P. Rigby remarked that the smoothing machine used at Messrs. Chance's works had been adopted for giving the smoothness of polished plate glass to sheet glass, as that was now required for many purposes and particularly by photographers; but hand smoothing never made the surface quite so smooth and uniform as was done by the machine.

The Chairman proposed a vote of thanks to Mr. Pilkington for his paper, which was passed.

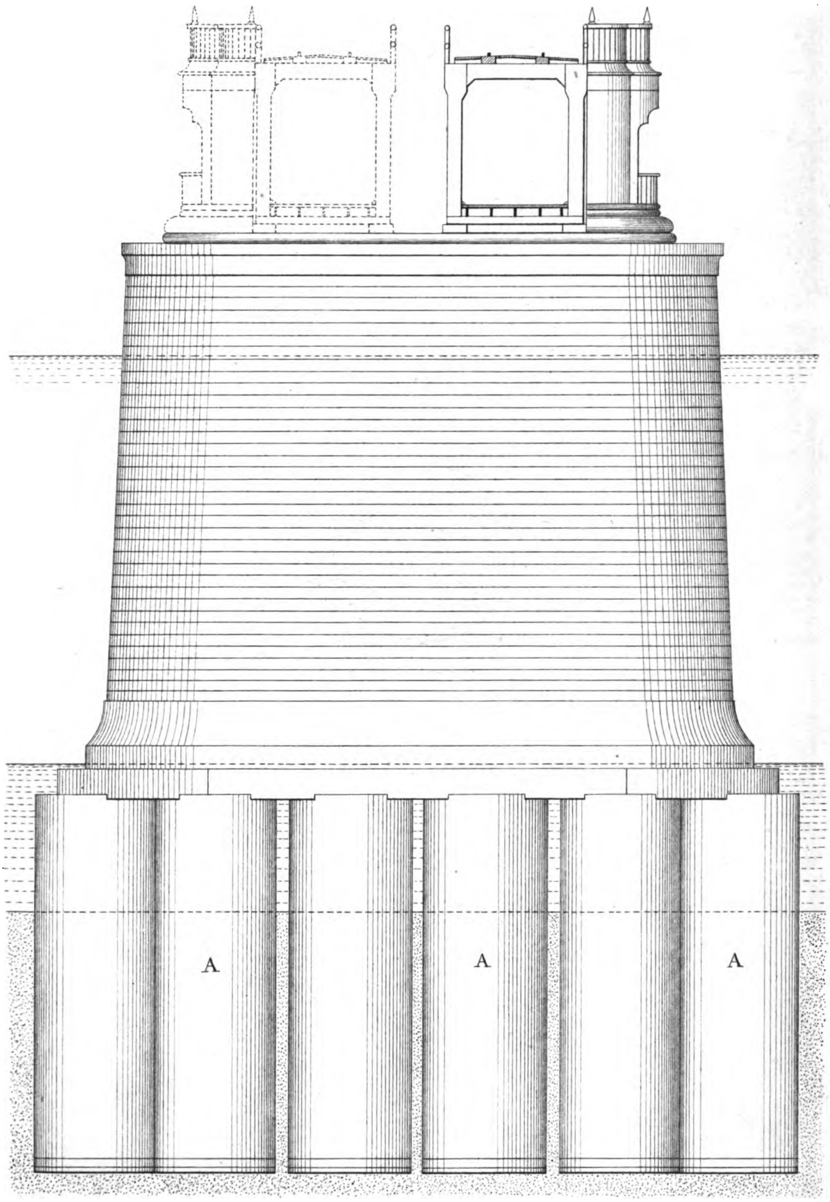
The Meeting then terminated.

INDIAN RAILWAY BRIDGE PIERS. Plate 1.



(Proceedings Inst. M.E. 1863. Page 16.)

Fig. 4. *Elevation of Pier, taken transversely of the bridge.*



Scale 1/260.th

(Proceedings Inst. M.E. 1863. Page 16.)

Fig. 5. *Vertical Section of Pier, taken longitudinally of the bridge.*

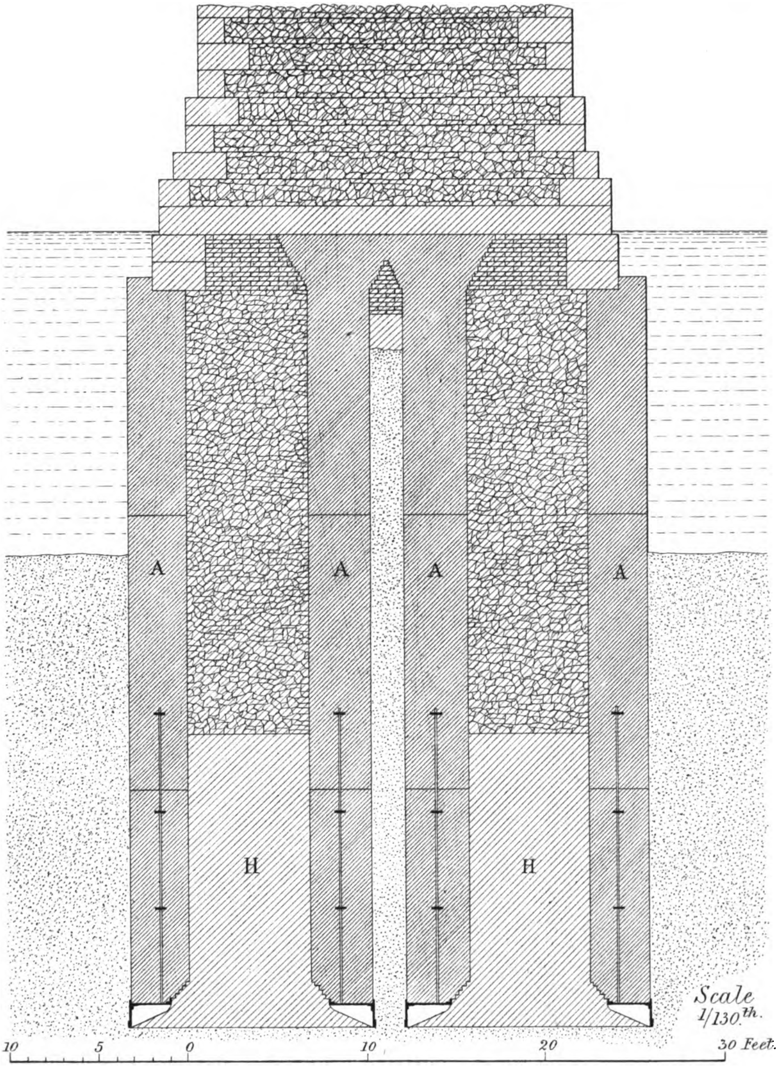
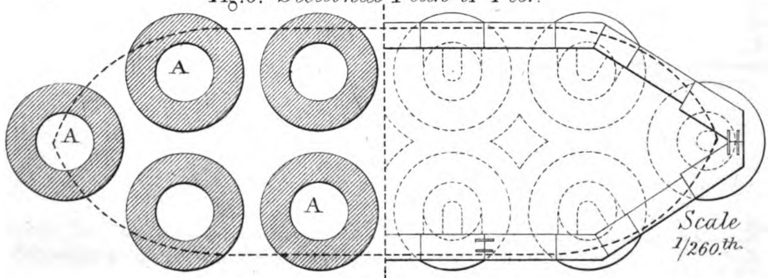
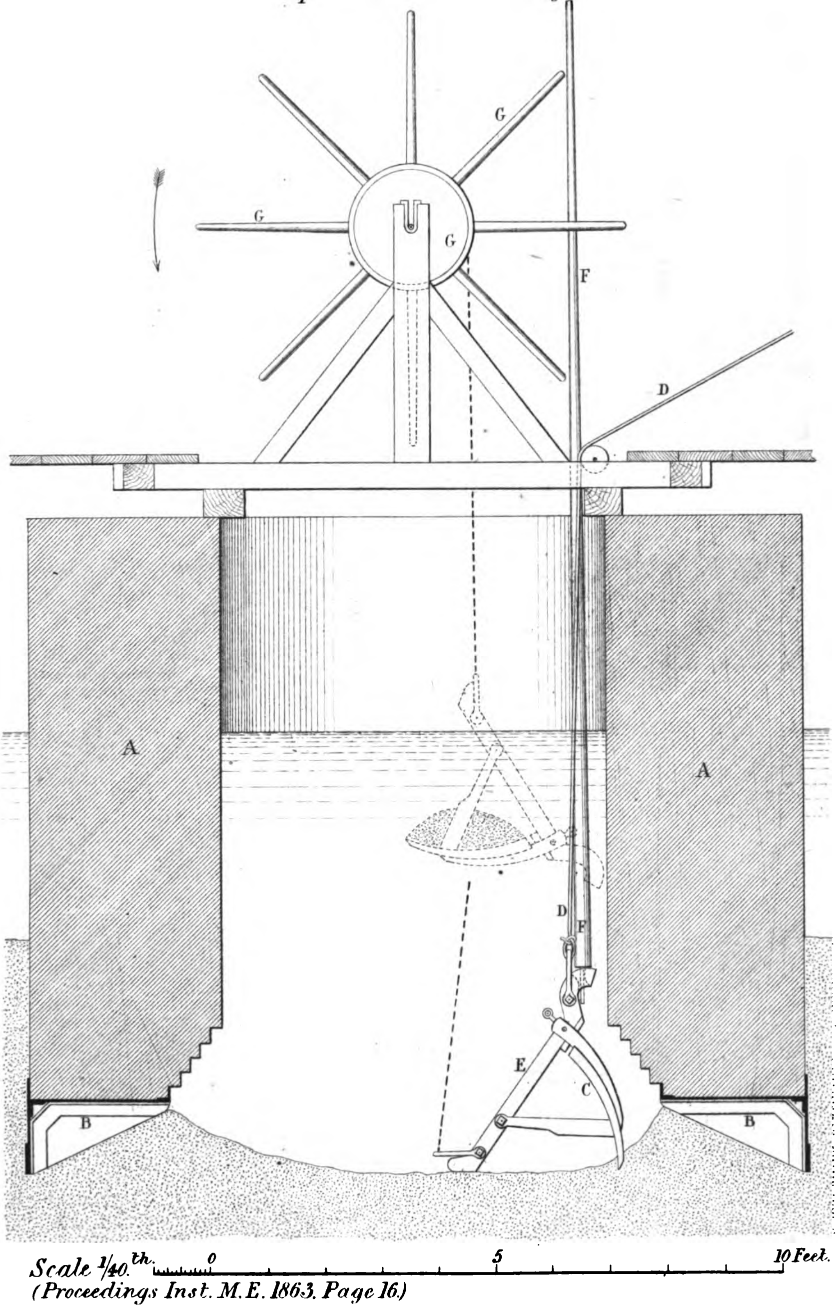


Fig. 6. *Sectional Plan of Pier.*



(Proceedings Inst. M.E. 1863. Page 16.)

Fig. 7. *Vertical Section of Brick Cylinder in process of sinking.*



(Proceedings Inst. M.E. 1863. Page 16.)

Vertical Sections of Brick Cylinder, showing mode of excavating by the Scoop.

Fig. 8.

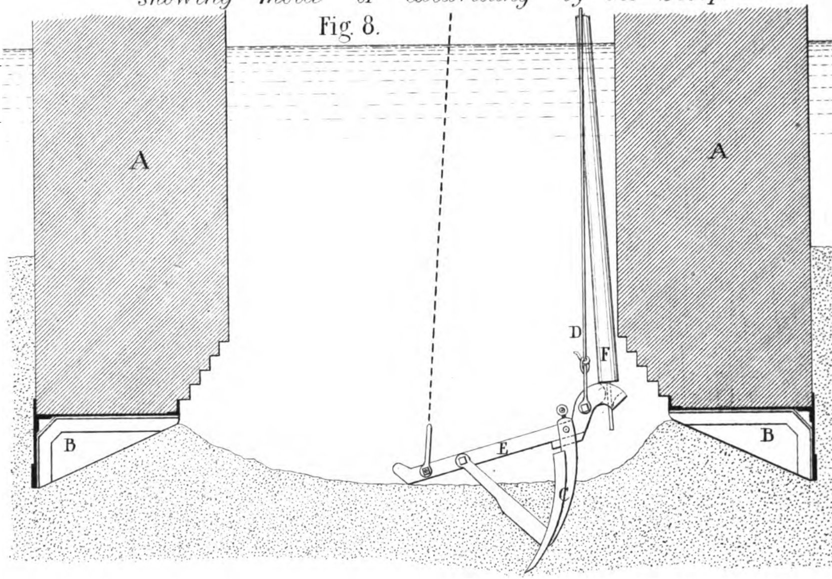


Fig. 9.

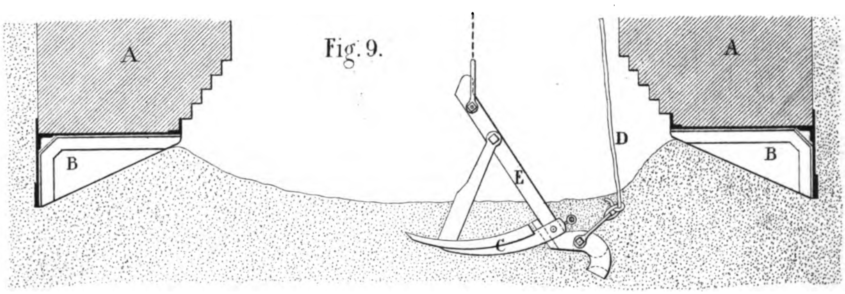
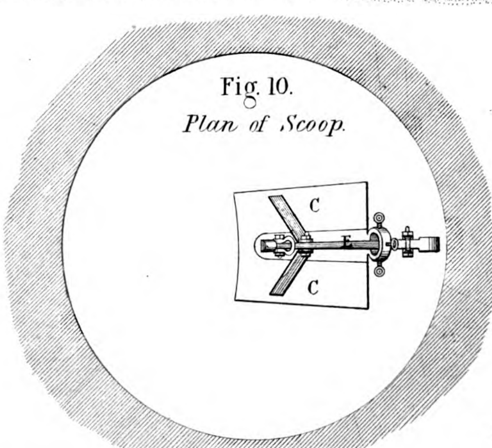


Fig. 10.

Plan of Scoop.



Scale 1/40th.

Ins.12 6 0 5 10 Feet.

Fig. 1. *Plan of Composing Machine.*

Fig. 2.

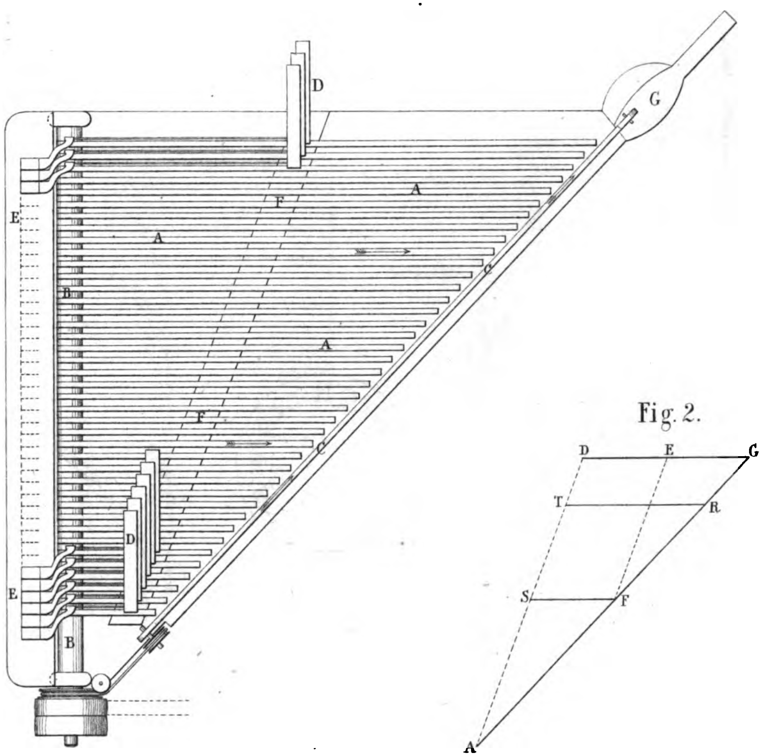
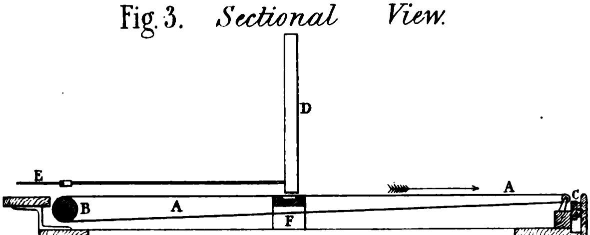


Fig. 3. *Sectional View.*



Scale 1/16th.

10 5 0 10 20 30 40 50 *Inches.*

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Plate 7.

Fig. 4. *Elevation of Key action.*

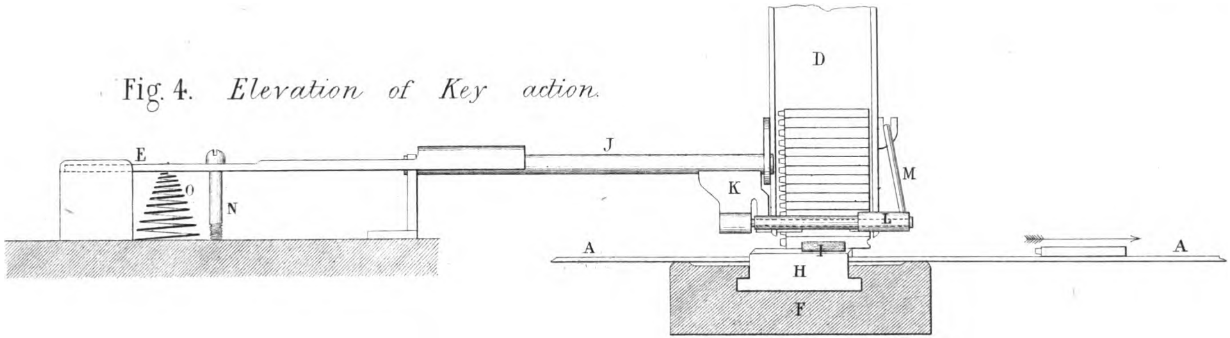
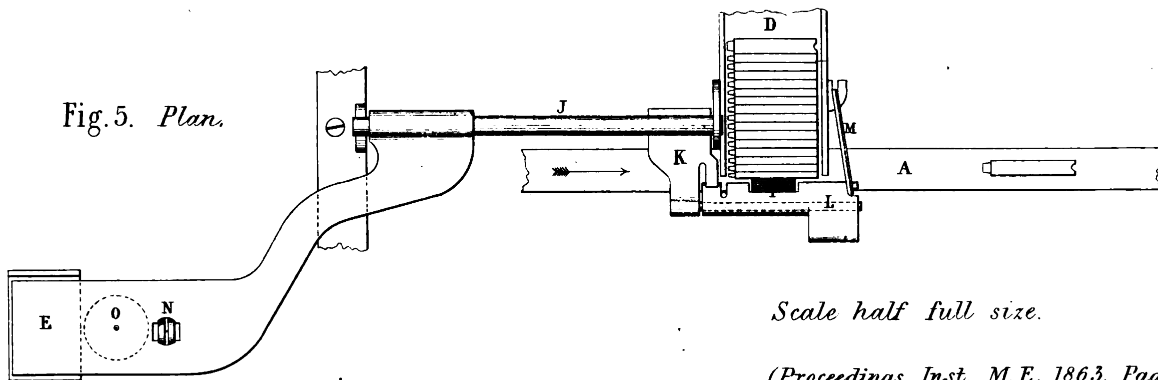


Fig. 5. *Plan.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Fig. 7. *Plan of Delivery of Types from parallel bands on to diagonal collecting band.*
Scale half full size.

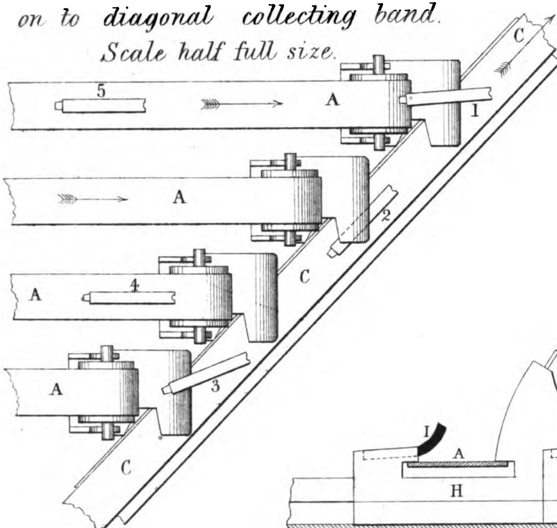
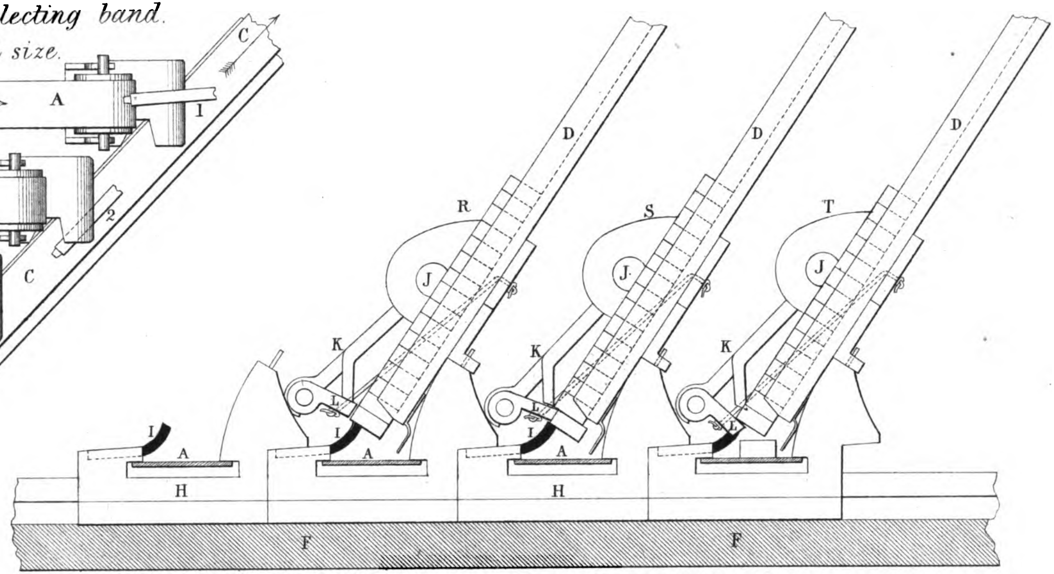


Fig. 6. *End View of Key action.*



Scale full size.

TYPE COMPOSING MACHINE.

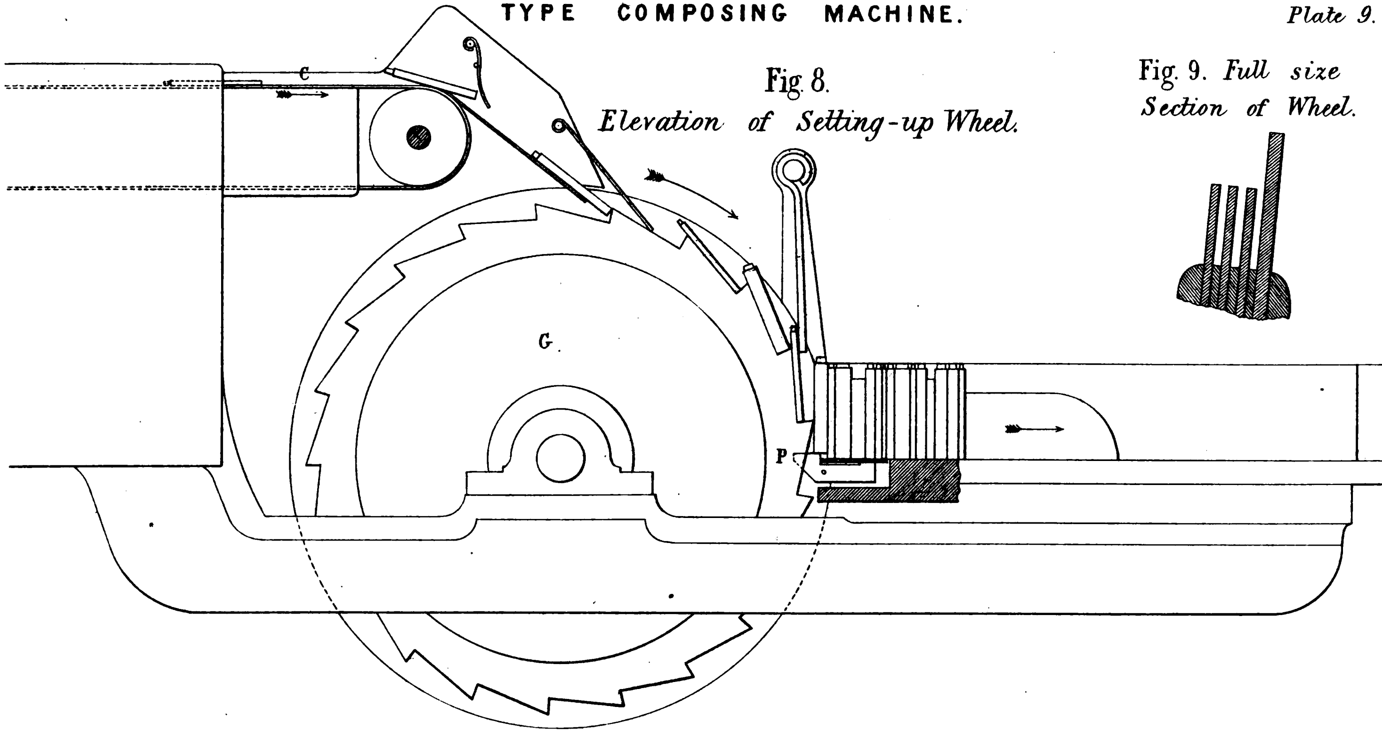


Fig. 8.
Elevation of Setting-up Wheel.

Fig. 9. *Full size*
Section of Wheel.

Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

Fig. 1. *Plan of Composing Machine.*

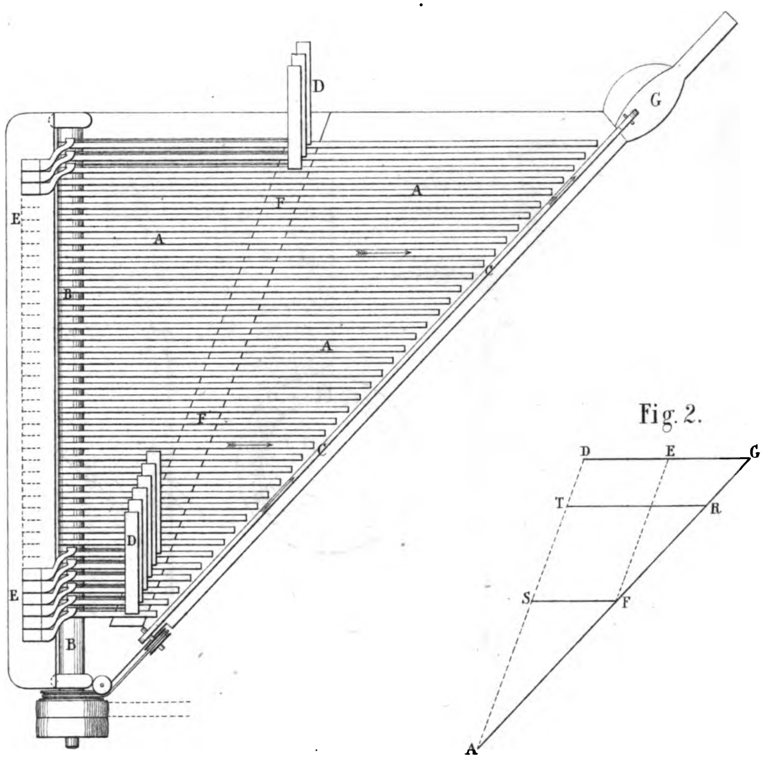
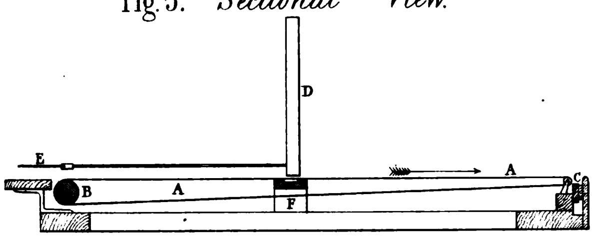
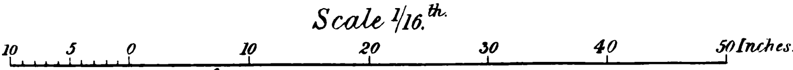


Fig. 3. *Sectional View.*



Scale 1/16.th



(Proceedings Inst. M.E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Fig. 4. *Elevation of Key action.*

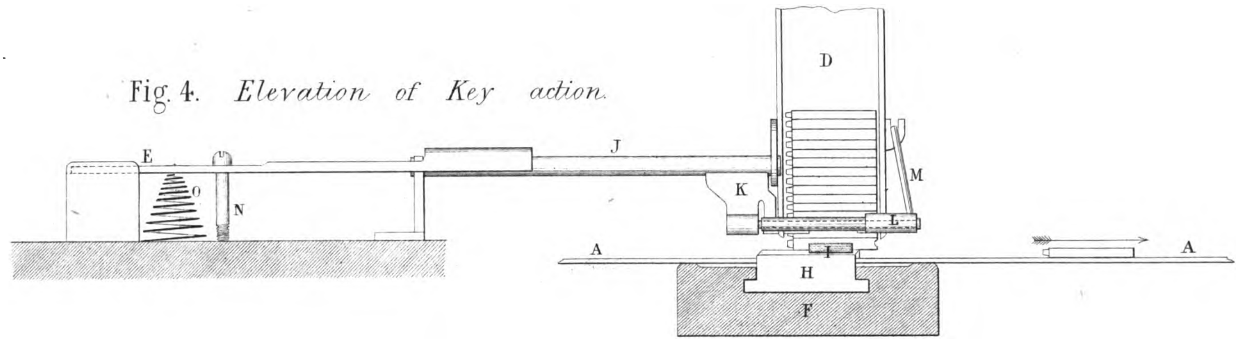
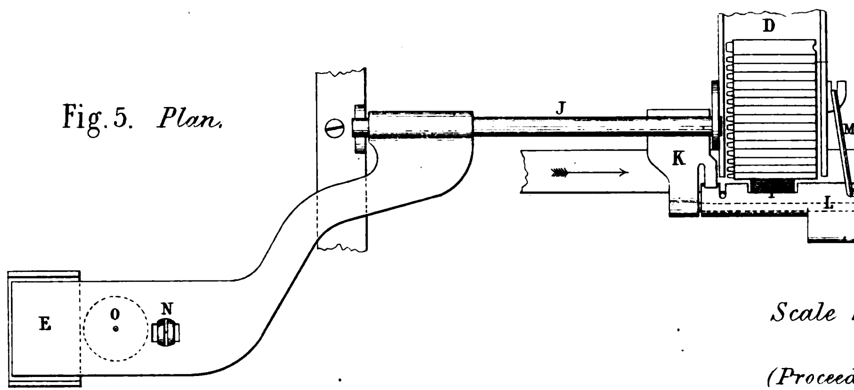


Fig. 5. *Plan.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

Fig. 7. *Plan of Delivery of Types from parallel bands on to diagonal collecting band.*
Scale half full size.

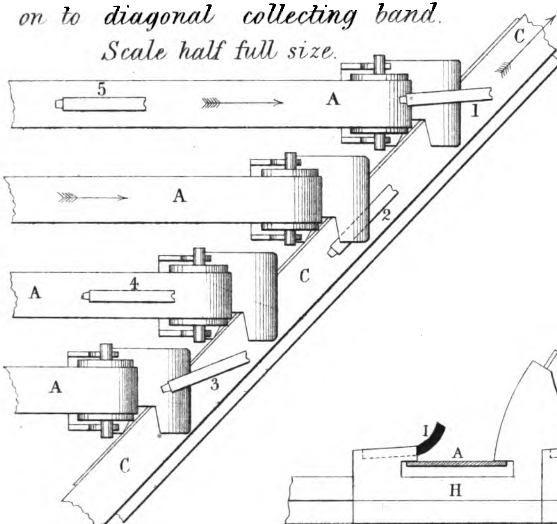
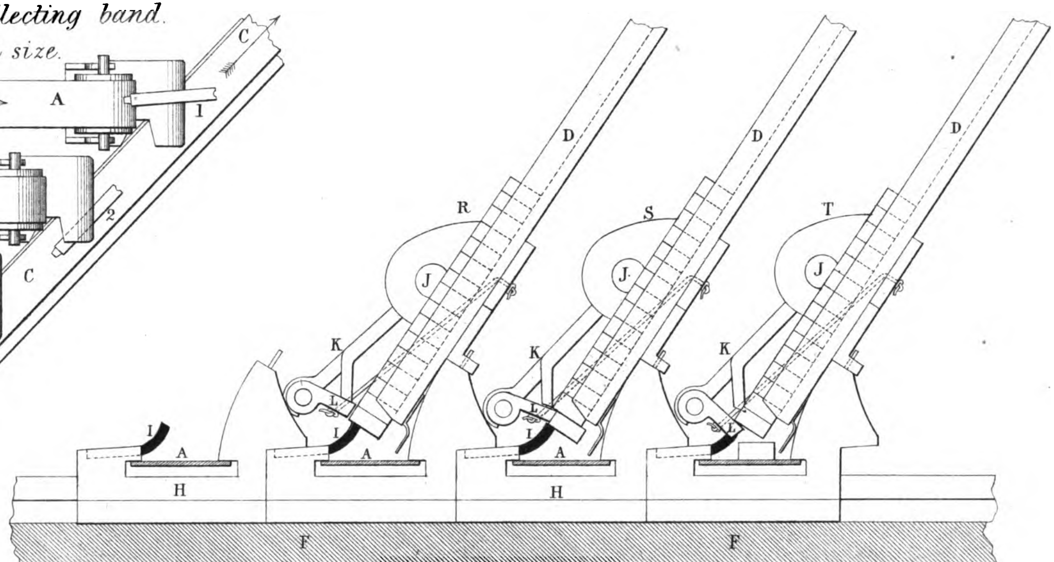


Fig. 6. *End View of Key action.*



Scale full size.

TYPE COMPOSING MACHINE. Plate 9.

Fig 8.
Elevation of Setting-up Wheel.

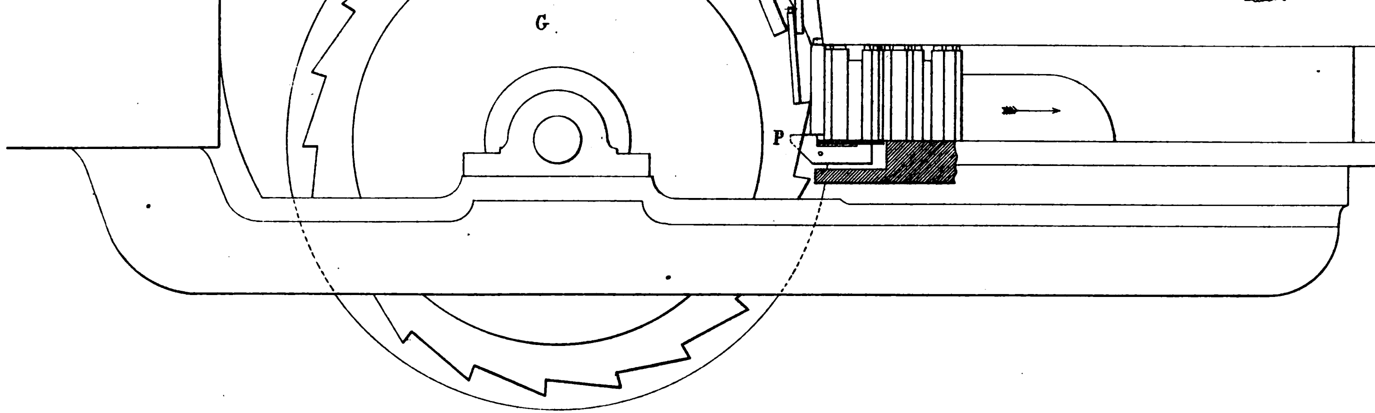


Fig. 9. *Full size Section of Wheel.*

Scale half full size.

Fig. 1. *Plan of Composing Machine.*

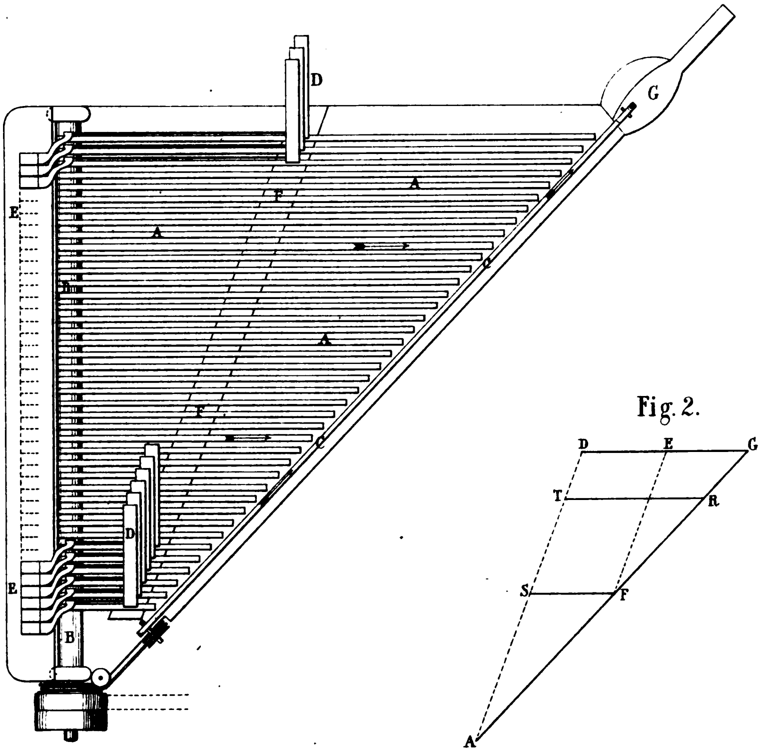
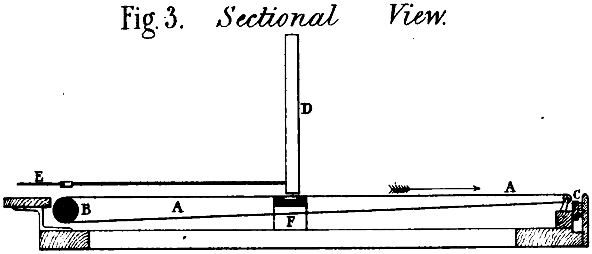
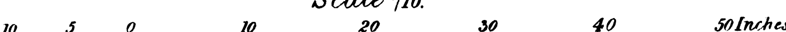


Fig. 3. *Sectional View.*



Scale 1/16th.



(Proceedings Inst. M.E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Fig. 4. *Elevation of Key action.*

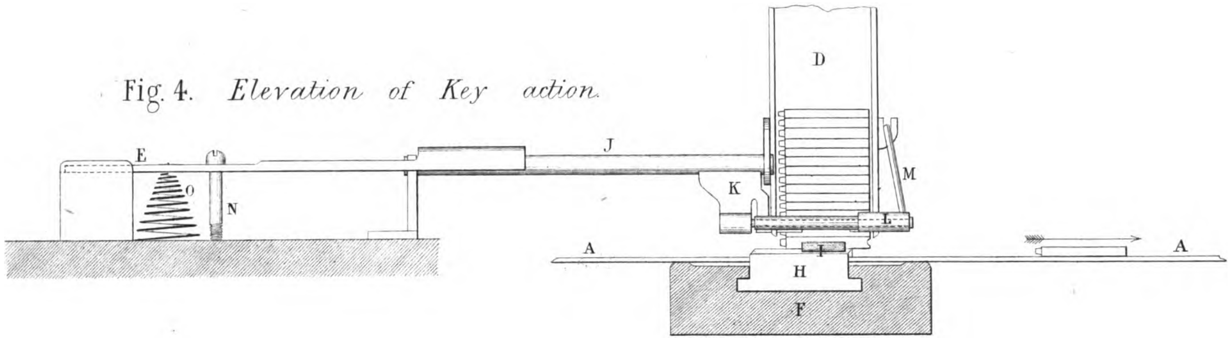
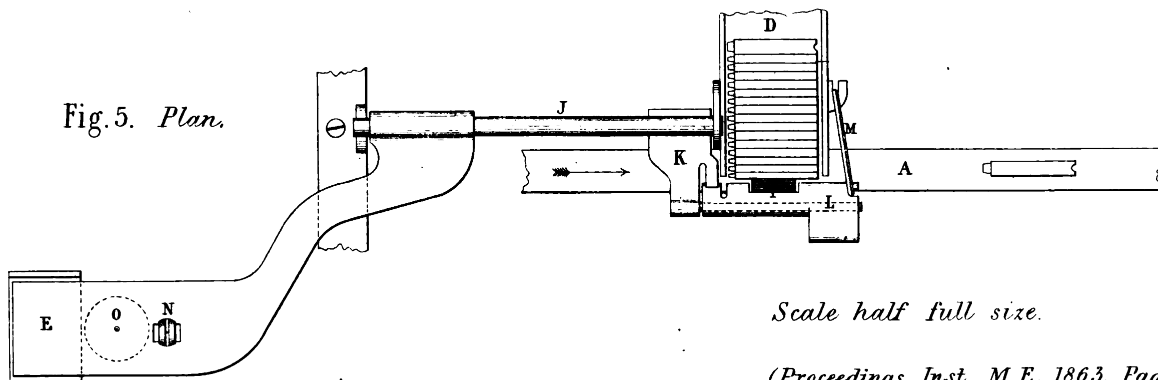


Fig. 5. *Plan.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Plate 8.

Fig. 7. *Plan of Delivery of Types from parallel bands on to diagonal collecting band.*

Scale half full size.

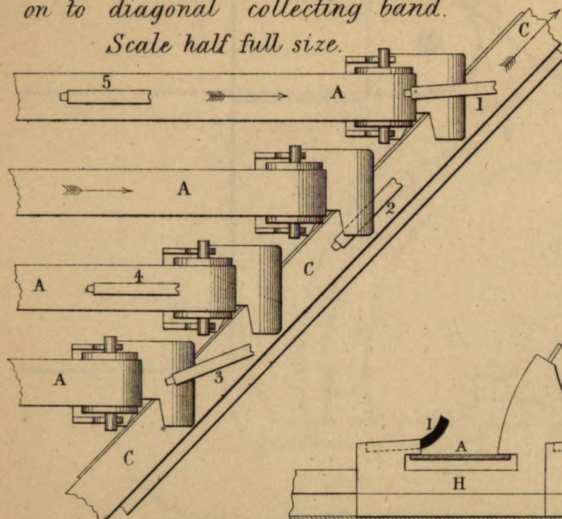
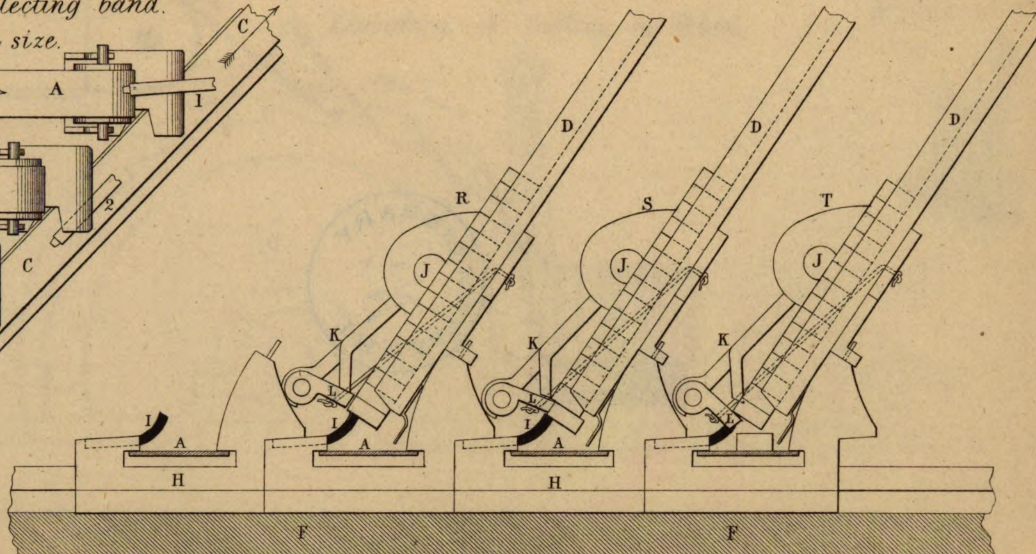


Fig. 6. *End View of Key action.*



Scale full size.

(Proceedings Inst. M. E. 1863. Page 34.)

TYPE COMPOSING MACHINE.

Plate 9.

Fig. 8.
Elevation of Setting-up Wheel.

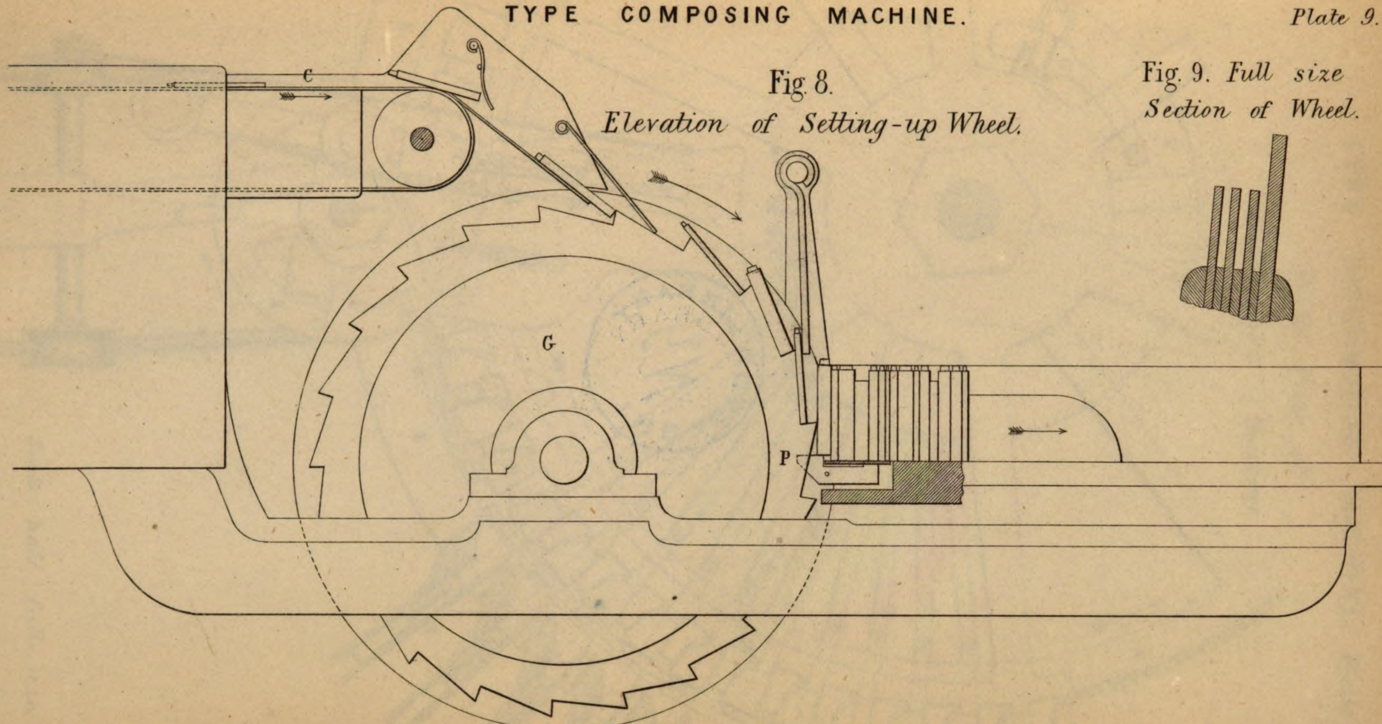


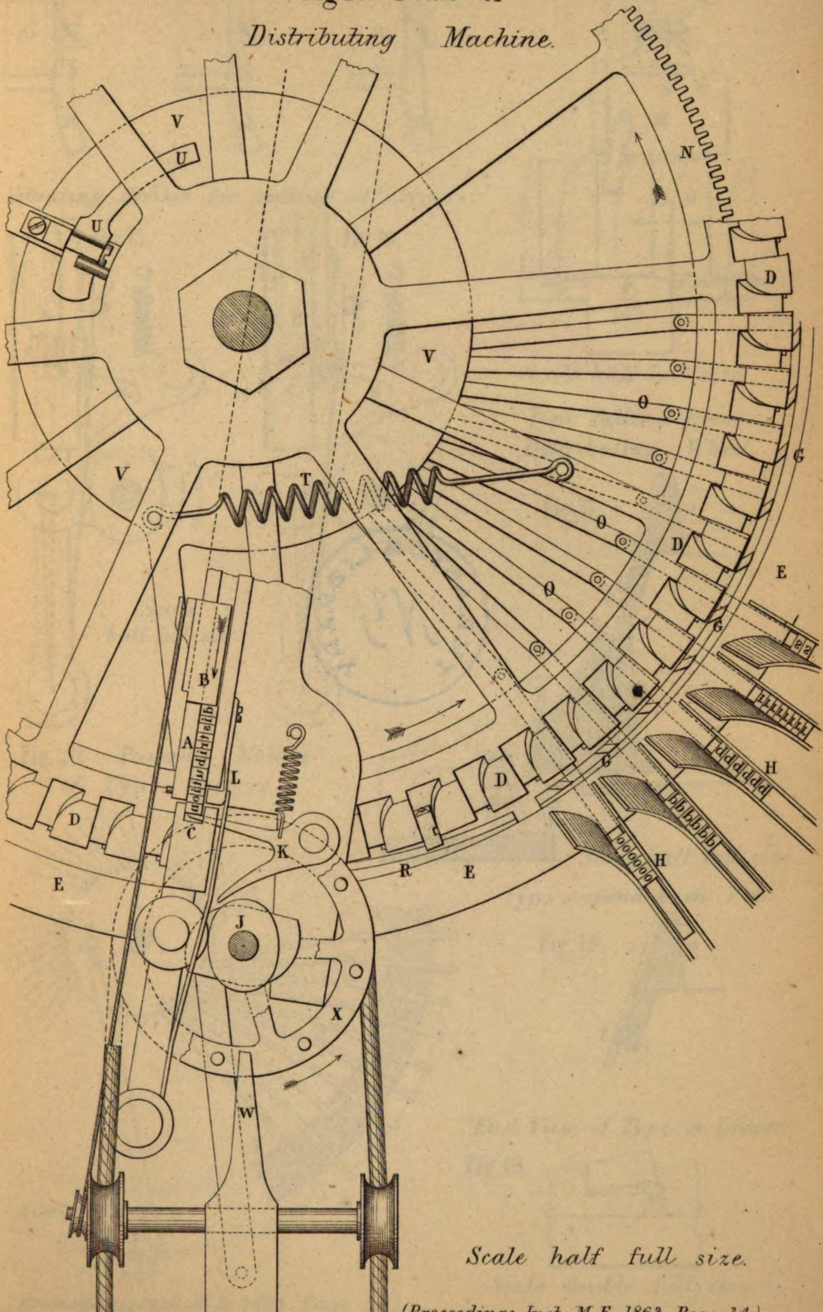
Fig. 9. *Full size*
Section of Wheel.

Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

TYPE DISTRIBUTING MACHINE. *Plate 10.*

Fig. 10. *Plan of Distributing Machine.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 34.)

Stop Plate for cutting off only one type at a time.

Fig. 11. Fig. 12. Fig. 13.

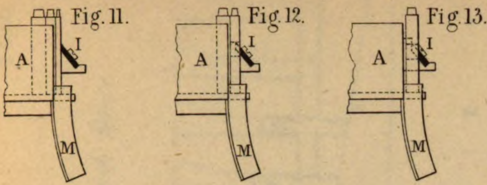
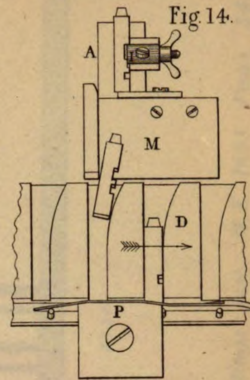


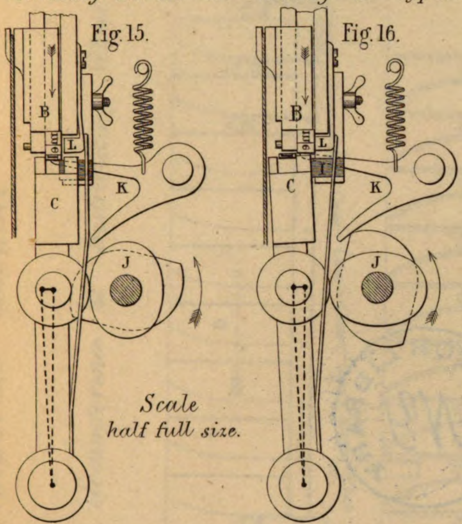
Fig. 14.



Scale half full size.

Vibrating Striker for cutting off types.

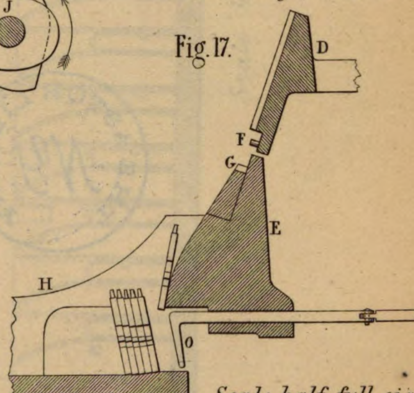
Fig. 15. Fig. 16.



Scale half full size.

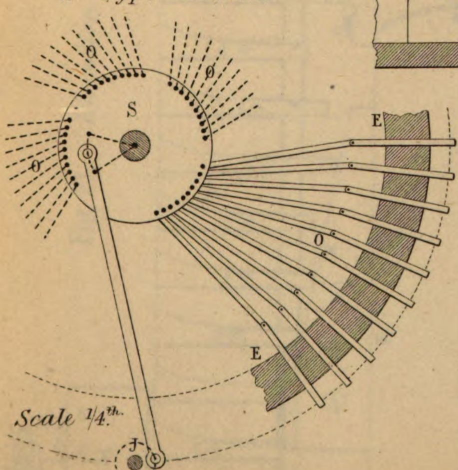
Type falling from Distributing Wheel.

Fig. 17.



Scale half full size.

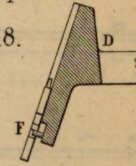
Fig. 20. *Pushing Motion of Type Drivers.*



Scale 1/4th.

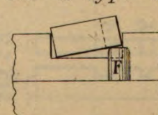
Type suspended on Pin.

Fig. 18.



End View of Type in Groove.

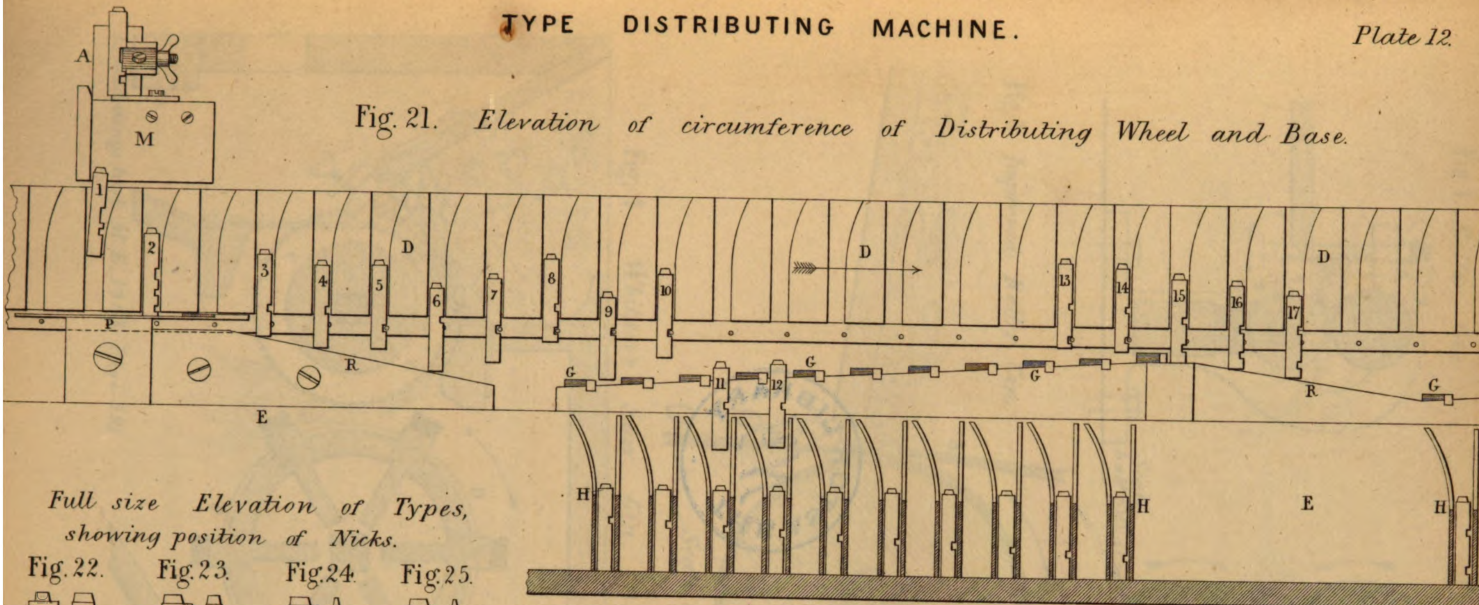
Fig. 19.



Scale double full size.

TYPE DISTRIBUTING MACHINE.

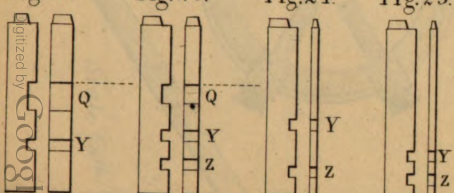
Fig. 21. *Elevation of circumference of Distributing Wheel and Base.*



Scale half full size.

Full size Elevation of Types, showing position of Nicks.

Fig. 22. Fig. 23. Fig. 24. Fig. 25.



(Proceedings Inst. M.E. 1863. Page 34.)

Fig. 1. *Roller Gin.*

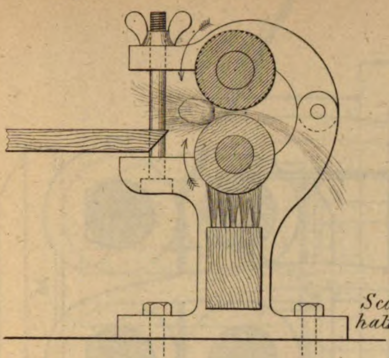


Fig. 2.

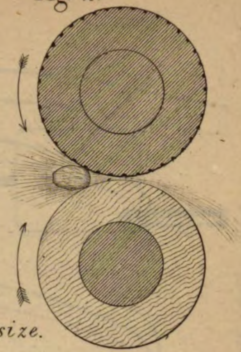


Fig. 3. *Improved Roller Gin.*

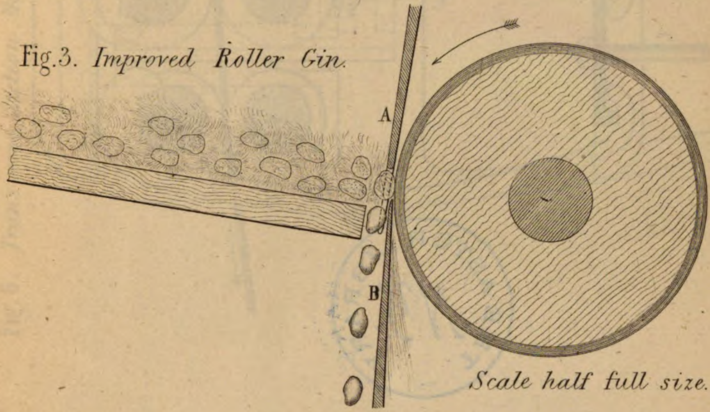
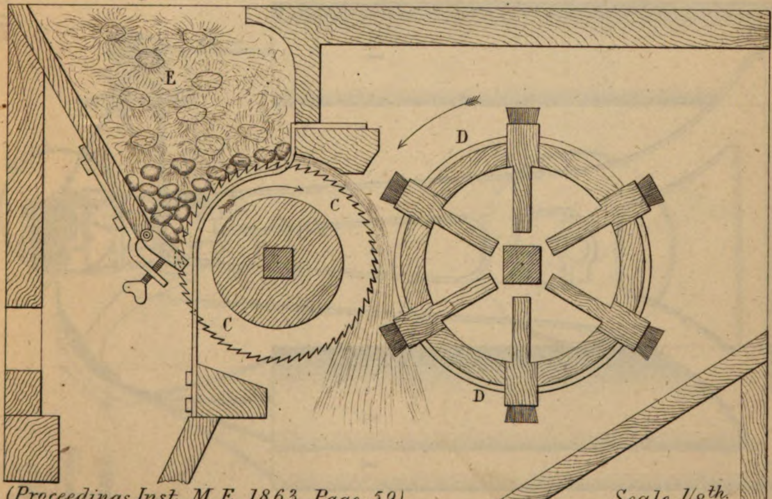


Fig. 4. *Whitney's Saw Gin.* 1793.



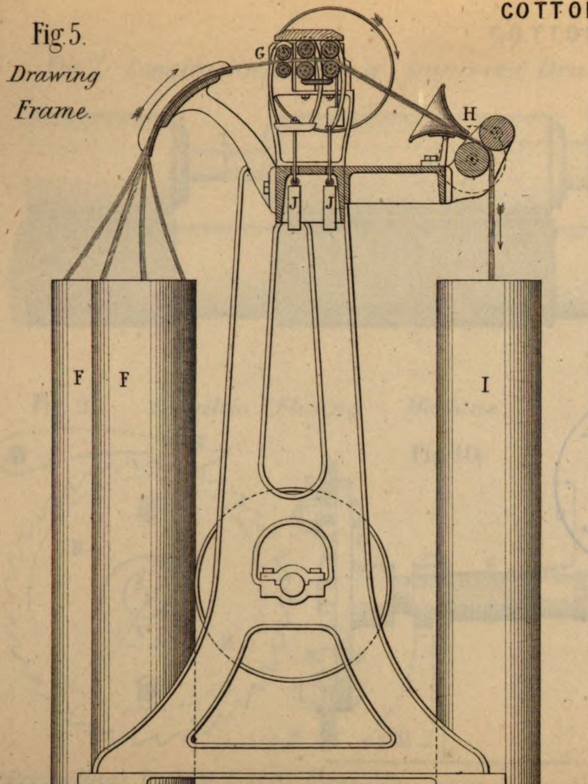
(Proceedings Inst. M.E. 1863. Page 59)

Scale 1/8th.

COTTON DRAWING ROLLERS.

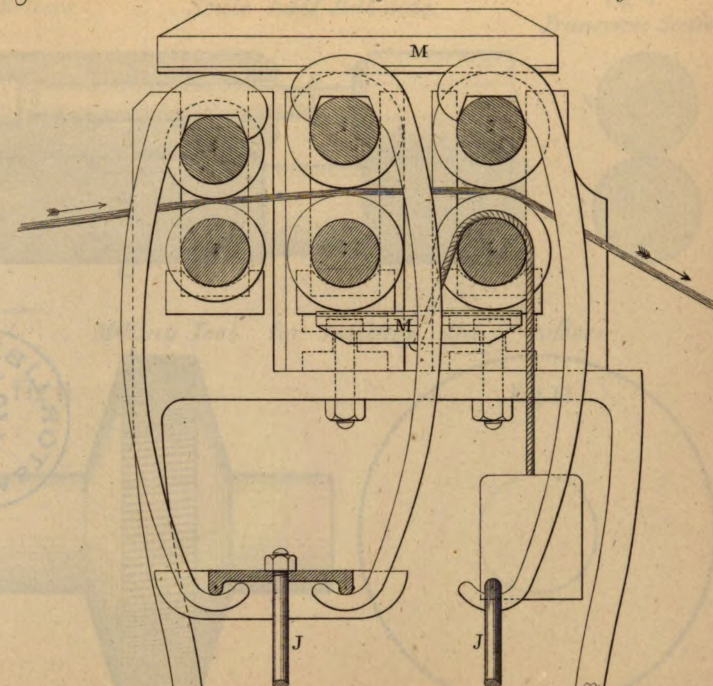
Plate 14.

Fig 5. *Drawing Frame.*



Scale 1/12th.

Fig. 6. *Transverse Section through centre of Drawing Rollers.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 59.)

Plate 15.

COTTON DRAWING ROLLERS.

Fig. 7. *Longitudinal View of improved Drawing Rollers.* *Scale half full size.*

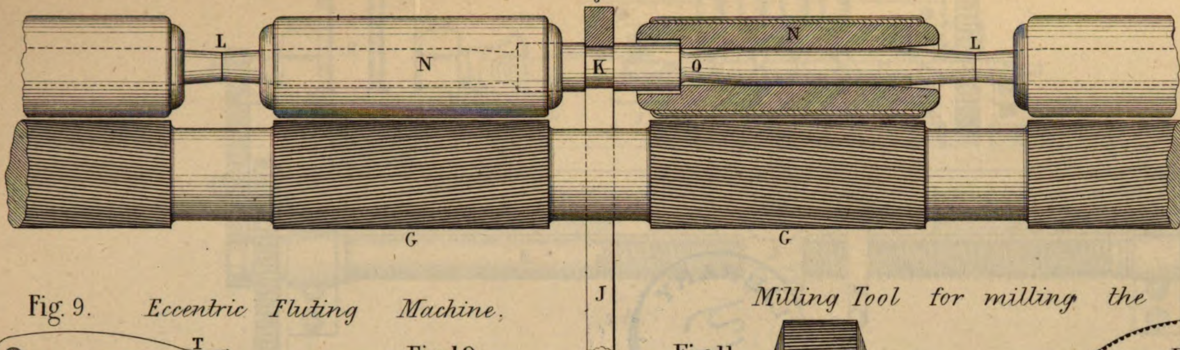


Fig. 8.

Transverse Section.

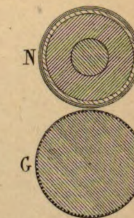
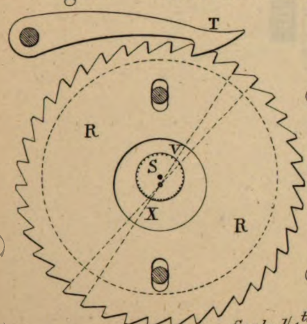
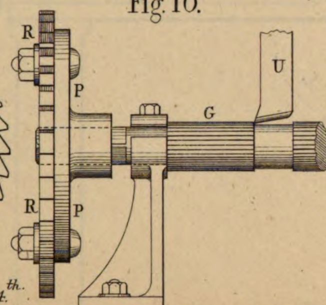


Fig. 9. *Eccentric Fluting Machine.*



Scale $1/4^{th}$.

Fig. 10.



Milling Tool for milling the rollers.

Fig. 11.

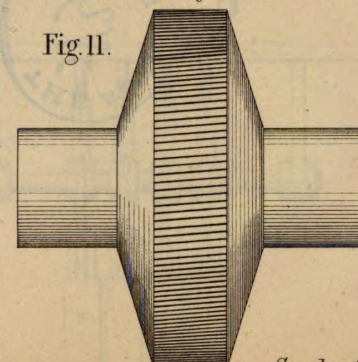
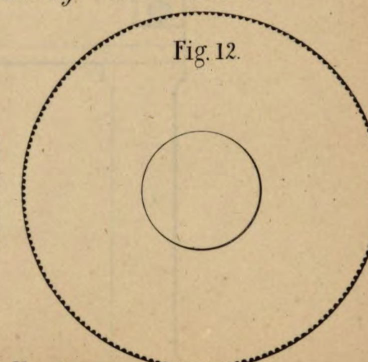


Fig. 12.

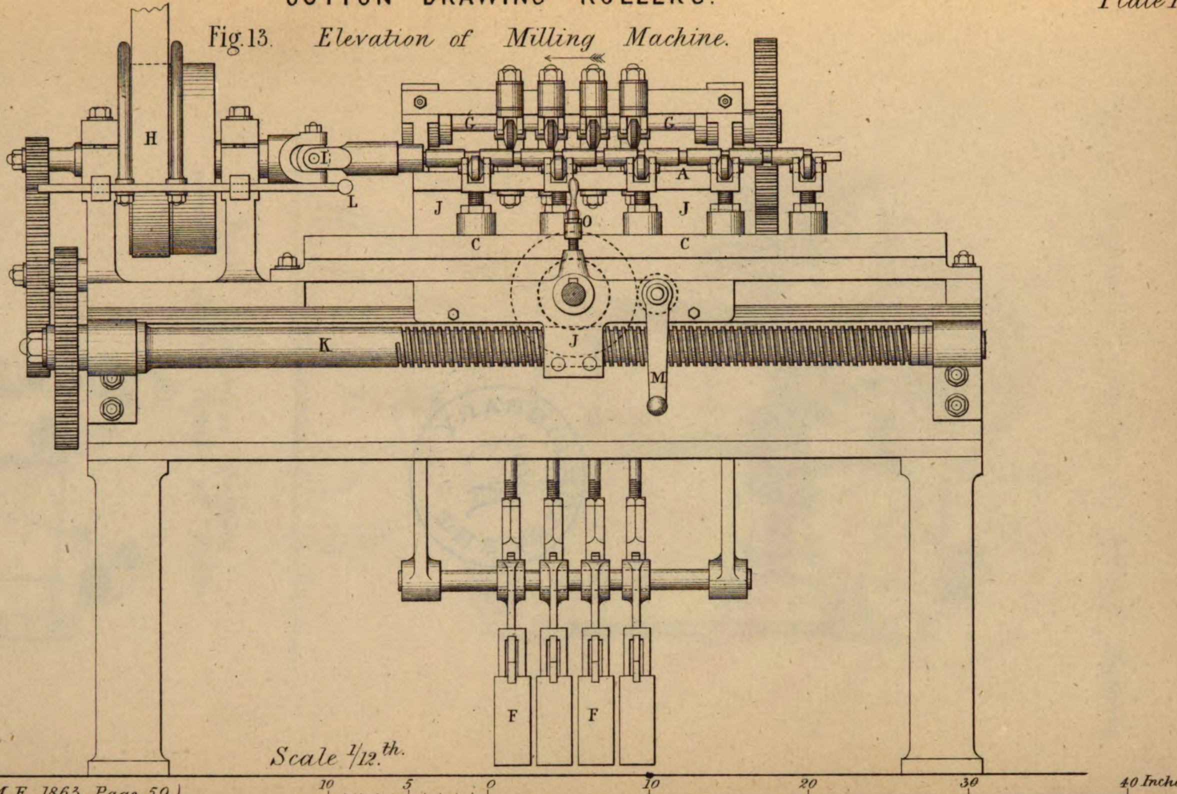


Scale full size.

(Proceedings Inst. M. E. 1863. Page 59.)

COTTON DRAWING ROLLERS.

Fig. 13. *Elevation of Milling Machine.*



Scale 1/12th.

Fig. 14. *Transverse Section of Milling Machine.*

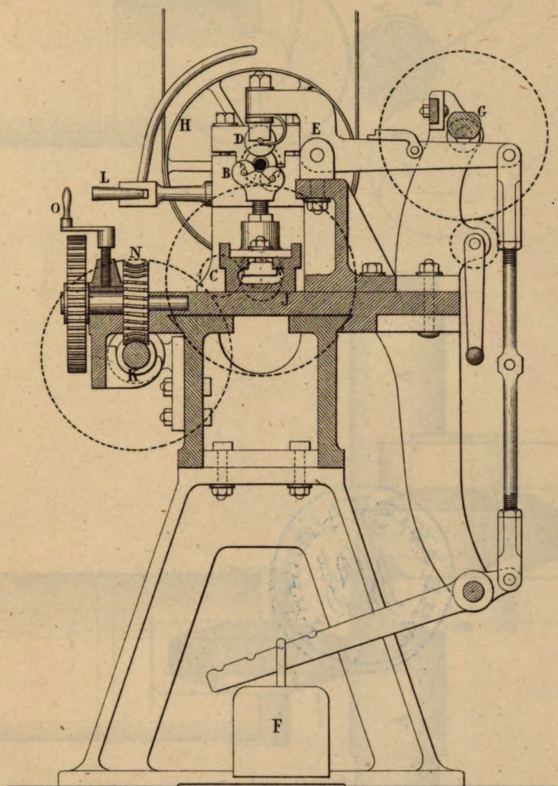
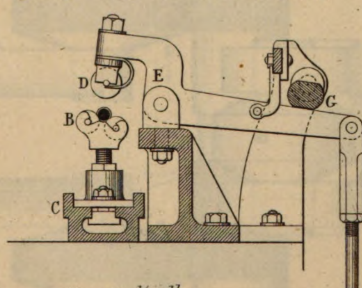


Fig. 15. *Transverse Section showing Mills lifted off Roller.*



Scale 1/12th.

10 5 0 10 20 30 *Inches.*

(Proceedings Inst. M.E. 1863. Page 59.)

COTTON DRAWING ROLLERS.

Plate 18.

Fig. 16. *Elevation of Milling Tools in action.*

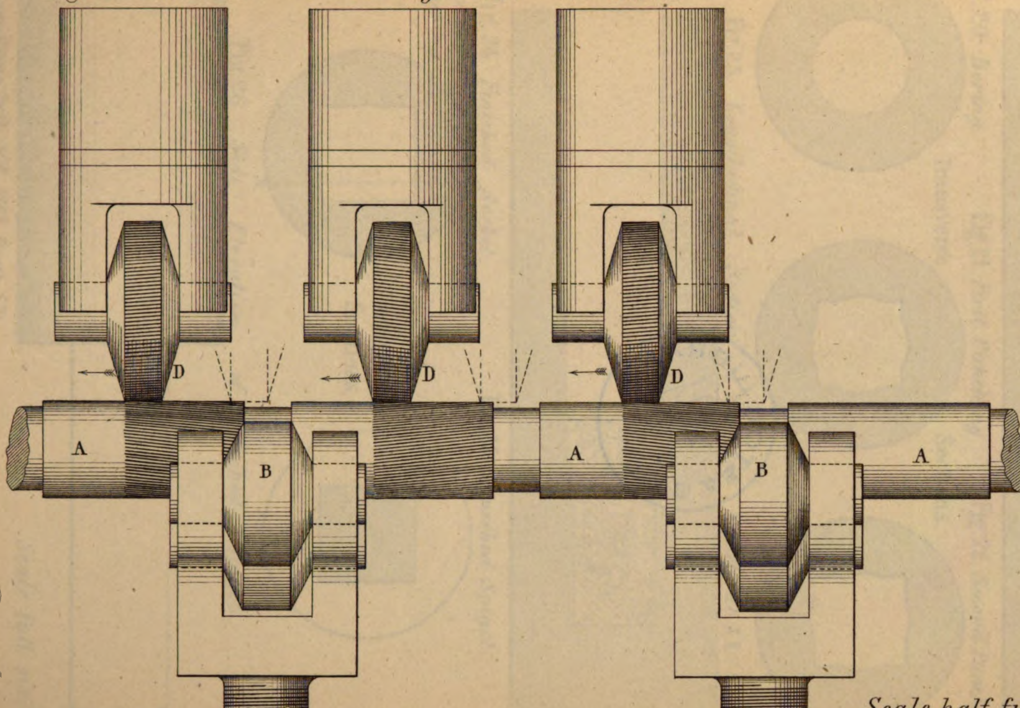
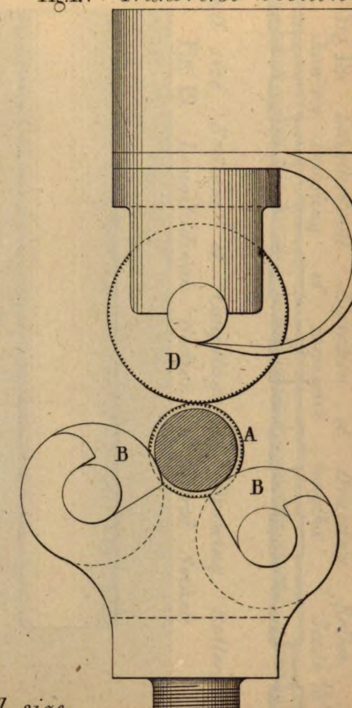


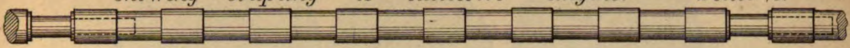
Fig. 17. *Transverse Section.*



Scale half full size.

(Proceedings Inst. M.E. 1863. Page 59.)

Fig. 18. *Longitudinal Elevation of Drawing Roller, showing Coupling of successive lengths.* *Scale 1/6th.*



Full size Sections of Couplings of Drawing Rollers.

Fig. 19. *Longitudinal Section of Bored Socket.*

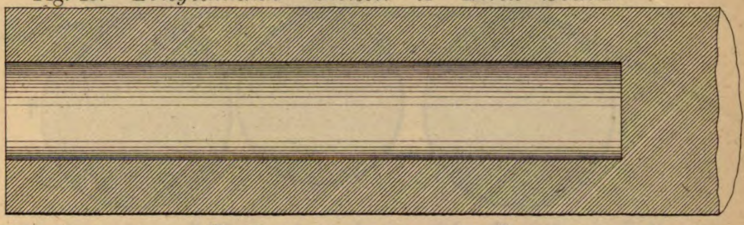


Fig. 20. *Boring.*

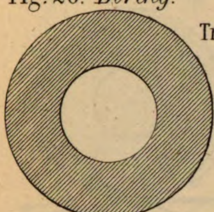


Fig. 21. *First Punching.*

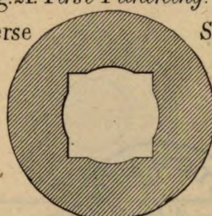
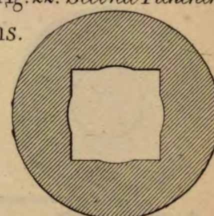


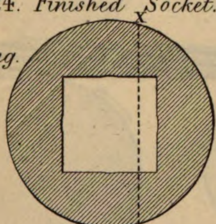
Fig. 22. *Second Punching.*



Transverse Sections.

Fig. 23. *Longitudinal Section of finished Socket at XX (Fig 24).*

Fig. 24. *Finished Socket.* *Third Punching.*



Transverse Sections.

Fig. 25. *Finished Spigot.*

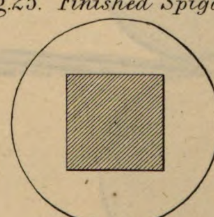
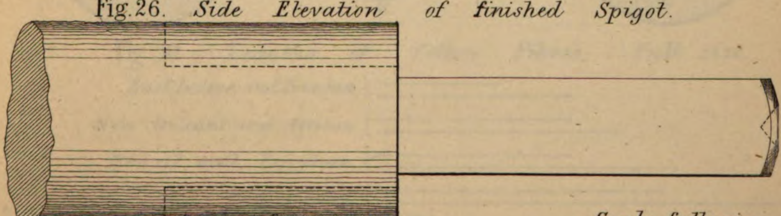


Fig. 26. *Side Elevation of finished Spigot.*



Scale full size.

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COTTON DRAWING ROLLERS

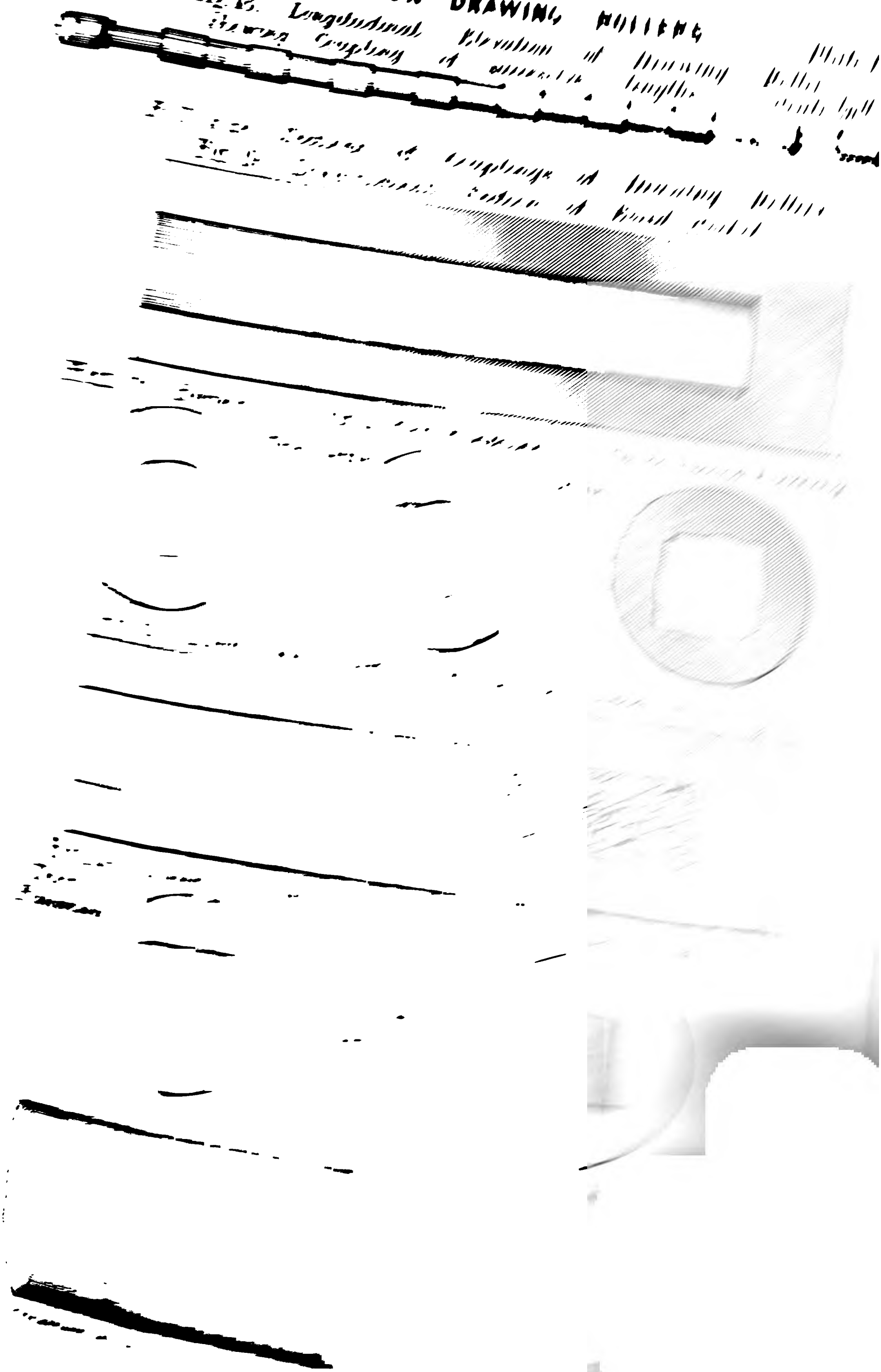
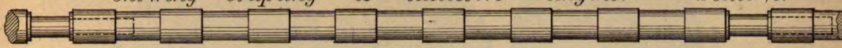


Fig. 18. *Longitudinal Elevation of Drawing Roller, showing Coupling of successive lengths. Scale 1/6th.*

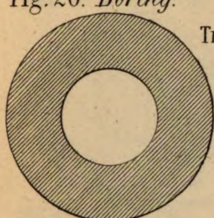


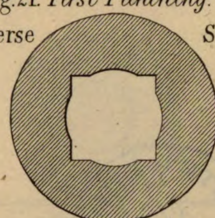
Full size Sections of Couplings of Drawing Rollers.

Fig. 19. *Longitudinal Section of Bored Socket.*

Fig. 20. *Boring.* Fig. 21. *First Punching.* Fig. 22. *Second Punching.*

Transverse Sections.





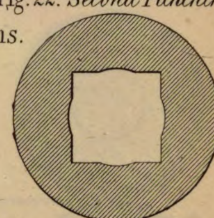
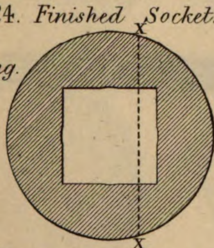


Fig. 23. *Longitudinal Section of finished Socket at XX (Fig 24).*

Fig. 24. *Finished Socket.* Fig. 25. *Finished Spigot.*

Third Punching.



Transverse Sections.

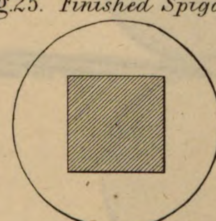
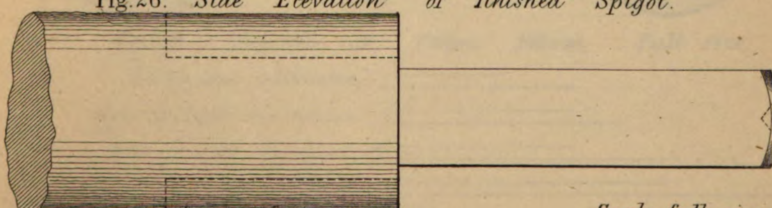


Fig. 26. *Side Elevation of finished Spigot.*



Scale full size.

(Proceedings Inst. M.E. 1863. Page 59)

Fig. 27. *Drawing Rollers for Short fibred cotton. Full size.*

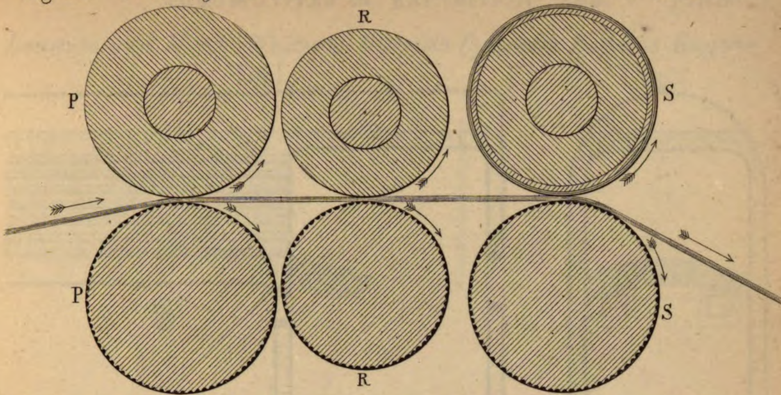


Fig. 28. *Drawing Rollers for Long fibred cotton. Full size.*

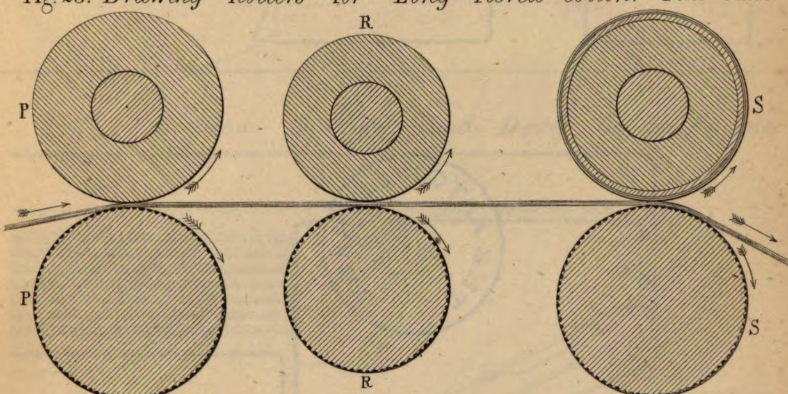


Fig. 29. *Diagram of Drawing Action.*

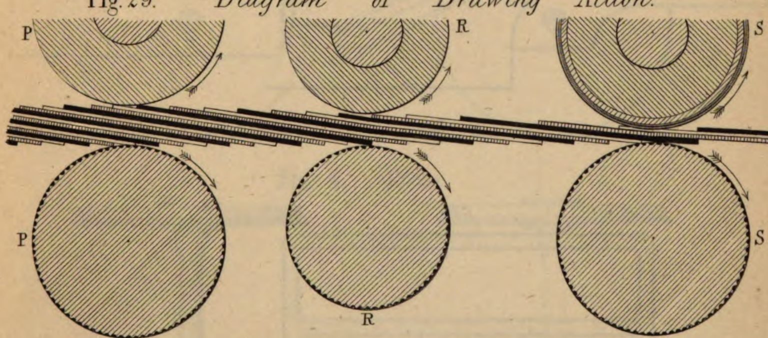
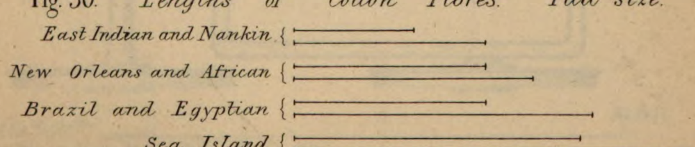


Fig. 30. *Lengths of Cotton Fibres. Full size.*



(Proceedings Inst. M. E. 1863. Page 59.)

London and North Western Outside Cylinder Express Engine.

Fig. 1.

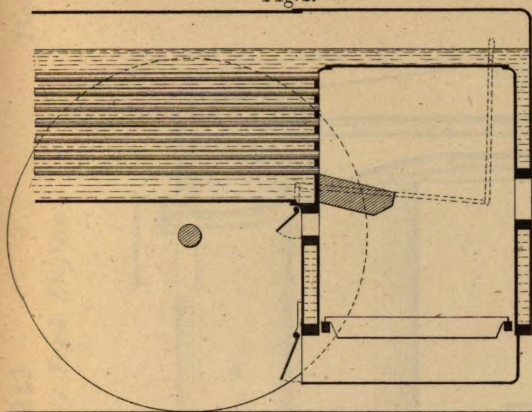


Fig. 2.

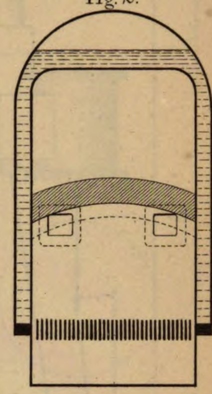


Fig. 3. *London Chatham and Dover Goods Engine.*

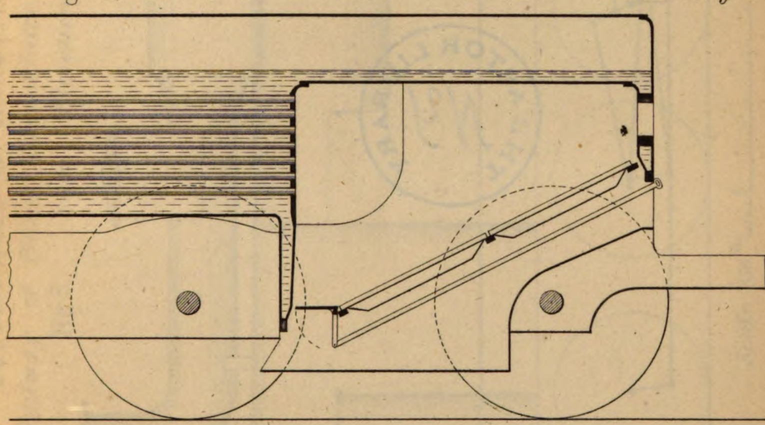
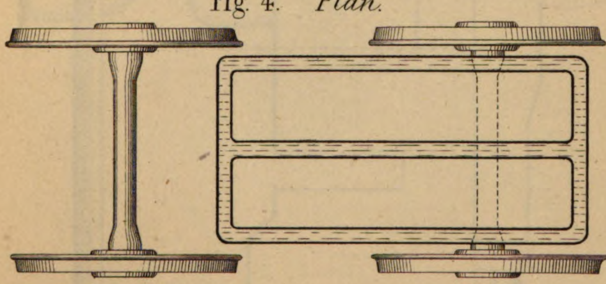


Fig. 4. *Plan.*



Scale 1/50th. 0 5 *10 Feet.*

(Proceedings Inst. M.E. 1863. Page 78.)

London and North Western Outside Cylinder Express Engine.

Fig. 1.

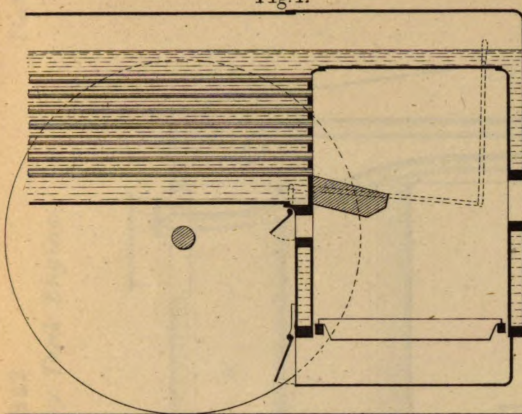


Fig. 2.

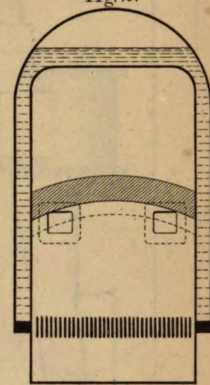


Fig. 3. *London Chatham and Dover Goods Engine.*

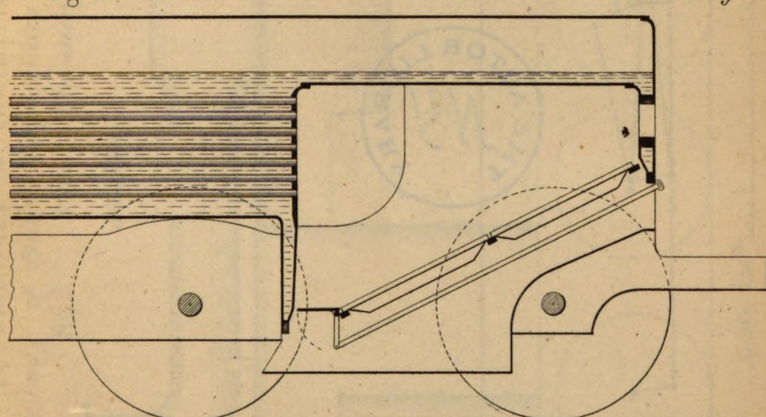
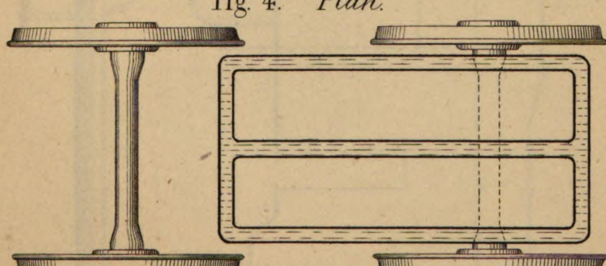


Fig. 4. *Plan.*



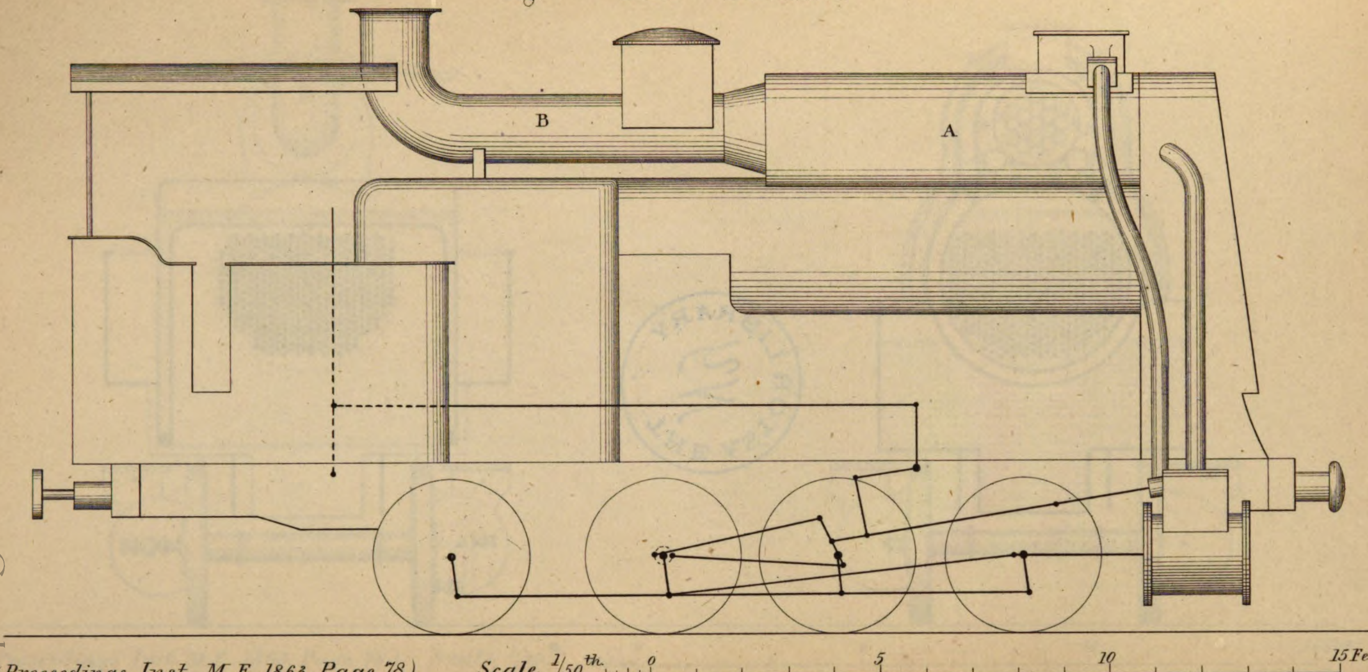
Scale 1/50th. 0 5 10 Feet.

(Proceedings Inst. M.E. 1863. Page 78.)

LOCOMOTIVES IN EXHIBITION 1862.

Northern Railway of France. "Dromadaire" Heavy Tank Engine.

Fig. 5. *Side Elevation.*



LOCOMOTIVES IN EXHIBITION 1862. Plate 23.

Northern Railway of France, "Dromadaire" Heavy Tank Engine.

Fig. 6. *Transverse Section through Firebox.*

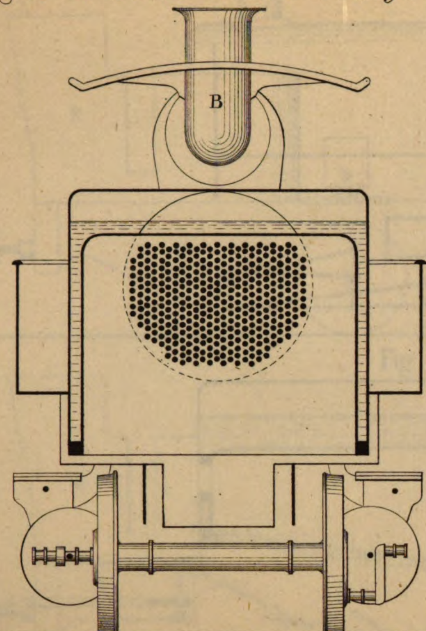
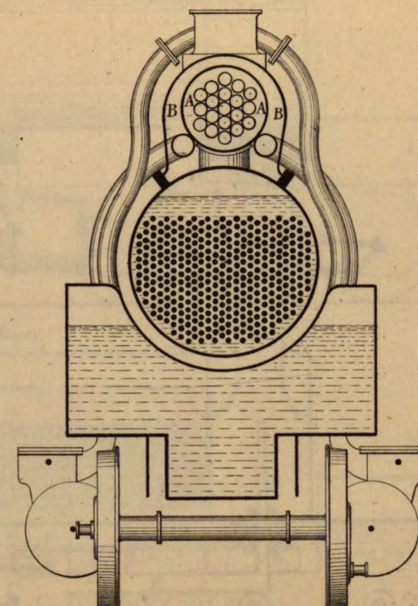


Fig. 7. *Transverse Section through Boiler.*



(Proceedings Inst. M.E. 1863. Page 78.) *Scale 1/50th.* 0 5 10 15 Feet.

LOCOMOTIVES IN EXHIBITION 1862,

Fig. 8. *Elevation of Meyer's Engine.*

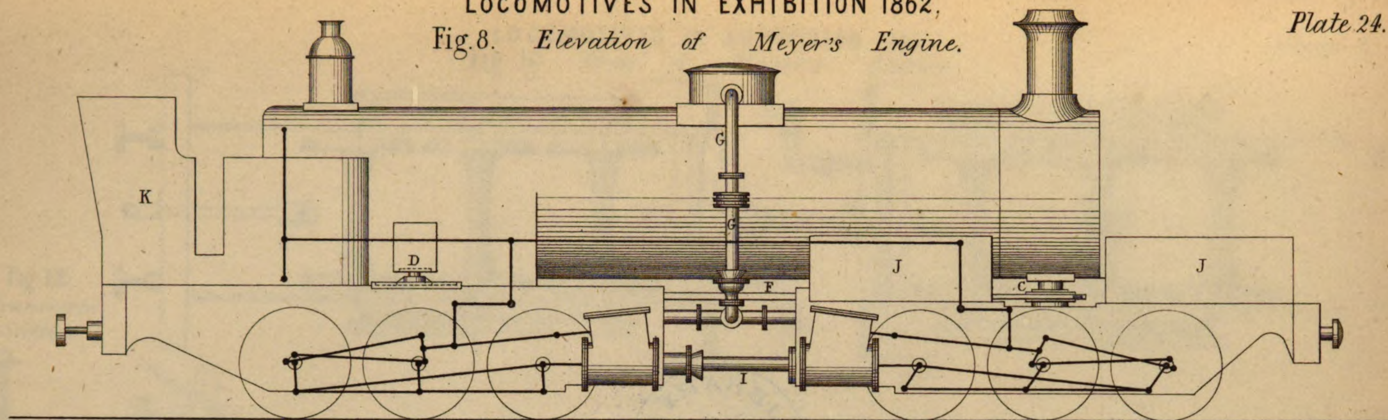
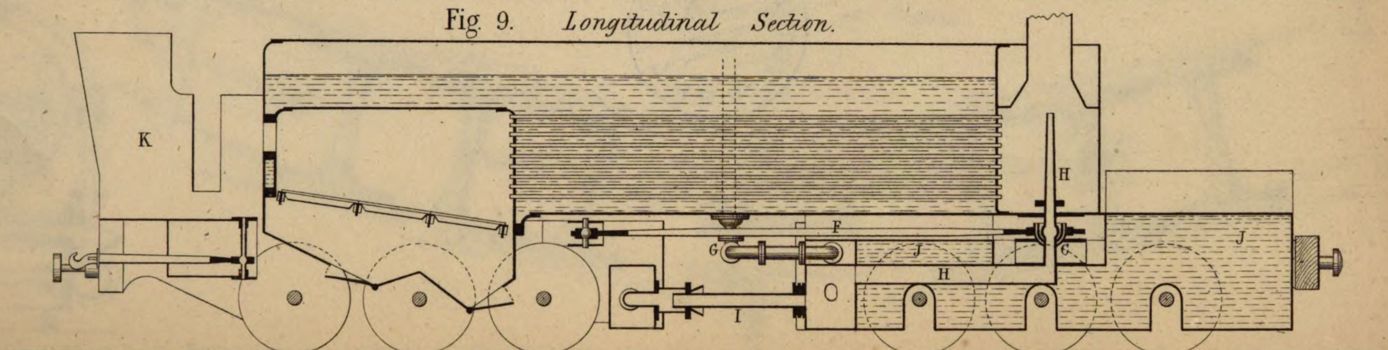


Fig. 9. *Longitudinal Section.*



Scale 1/80th.

0 5 10 15 20 Feet.

LOCOMOTIVES IN EXHIBITION 1862.

Plate 25.

Fig. 10. *Plan of Meyer's Engine.*

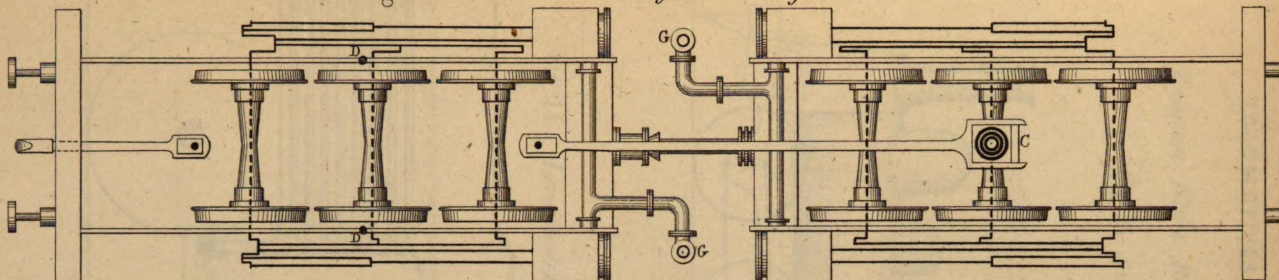


Fig. 12. *Transverse Section.*

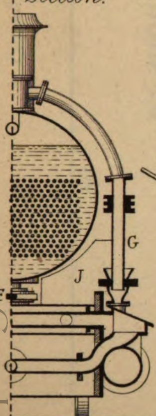
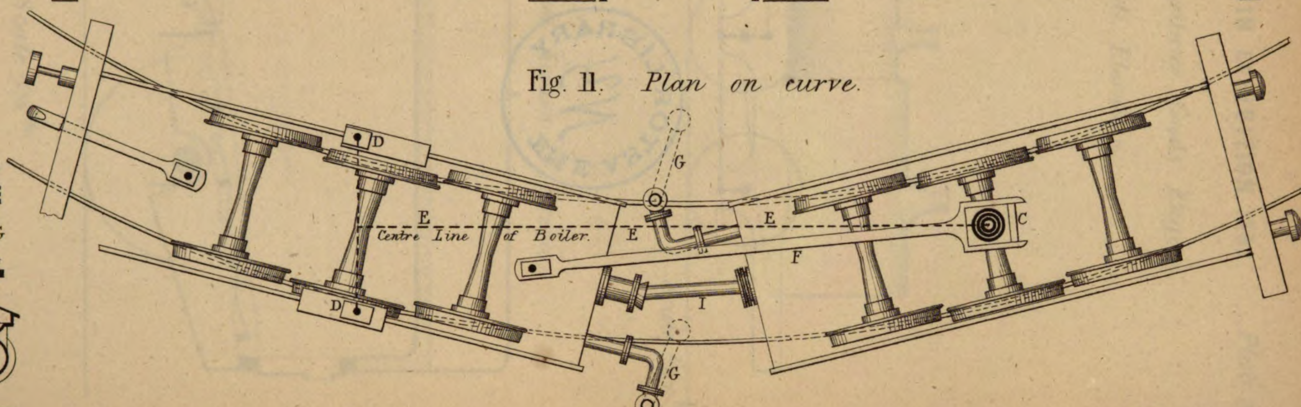


Fig. 11. *Plan on curve.*



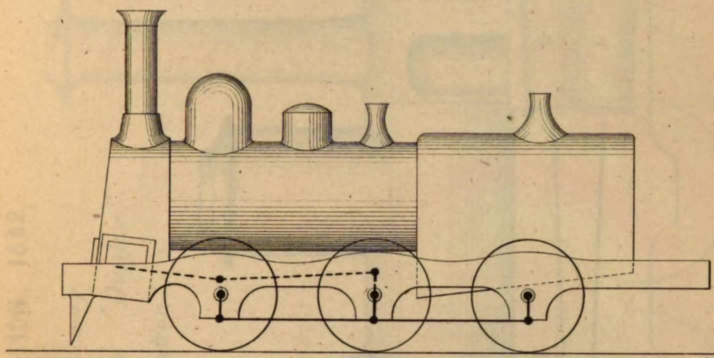
(Proceedings Inst. M.E. 1863. Page 78.)

Scale 1/80th.

0 5 10 15 20 Feet.

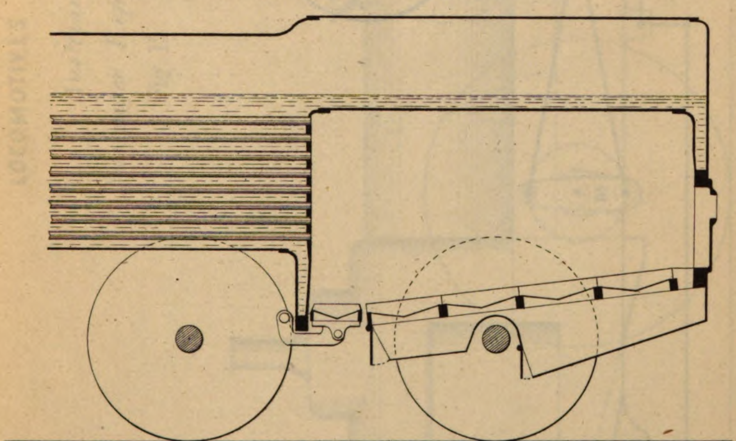
Belgian State Railway Goods Engine.

Fig. 13. *Side Elevation.*



Scale 1/100th.

Fig. 14. *Longitudinal Section of Firebox.*



Scale 1/50th.

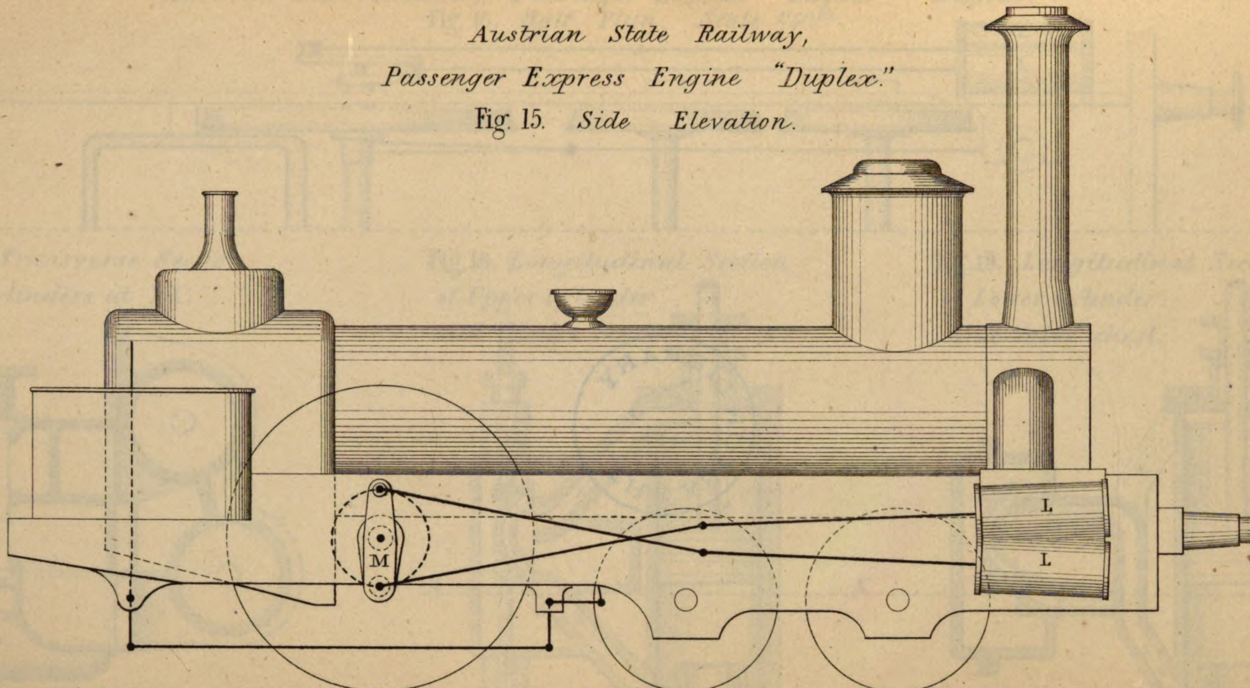
0 5 10 15 Feet.

LOCOMOTIVES IN EXHIBITION 1862.

Austrian State Railway,

Passenger Express Engine "Duplex."

Fig. 15. *Side Elevation.*



Scale 1/50th. 0 5 10 15 Feet.

LOCOMOTIVES IN EXHIBITION 1862.

Austrian State Railway, Passenger Express Engine "Duplex." *Plate 28.*

Fig. 16. *Half Plan. Scale 1/50th.*

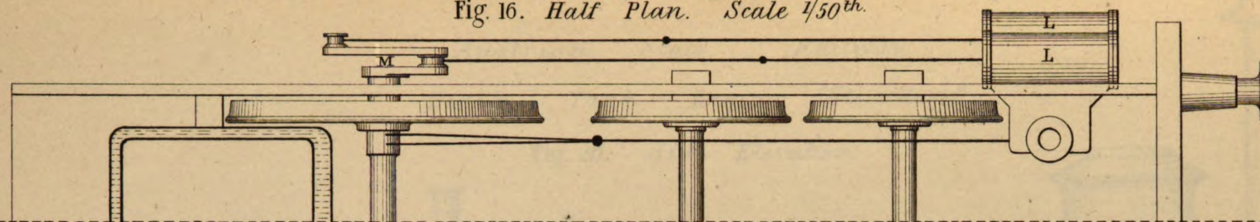


Fig. 17. *Transverse Section of Cylinders at XX.*

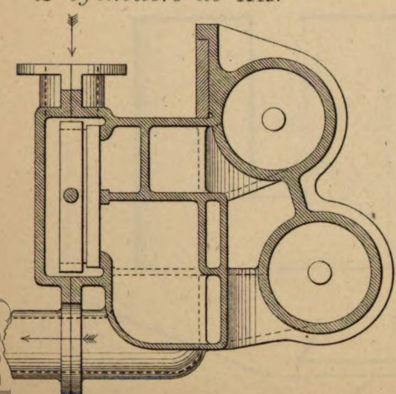
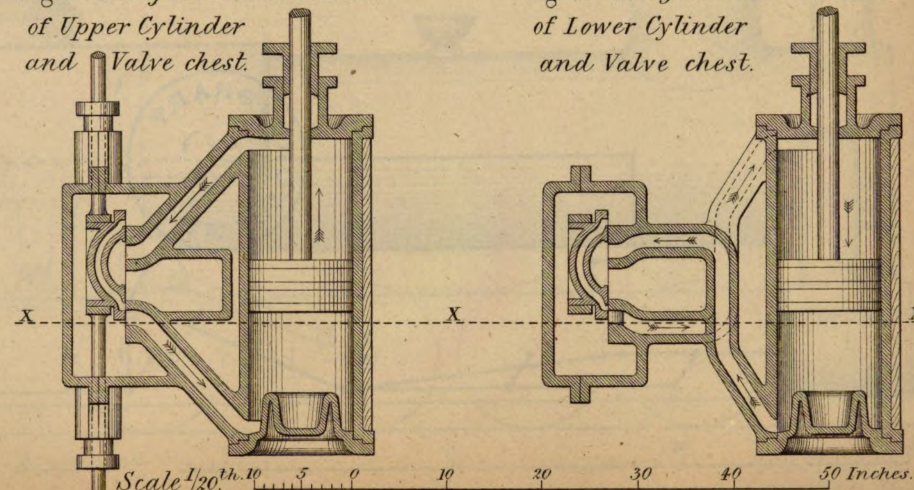


Fig. 18. *Longitudinal Section of Upper Cylinder and Valve chest.*

Fig. 19. *Longitudinal Section of Lower Cylinder and Valve chest.*



(Proceedings Inst. M.E. 1863. Page 78.)

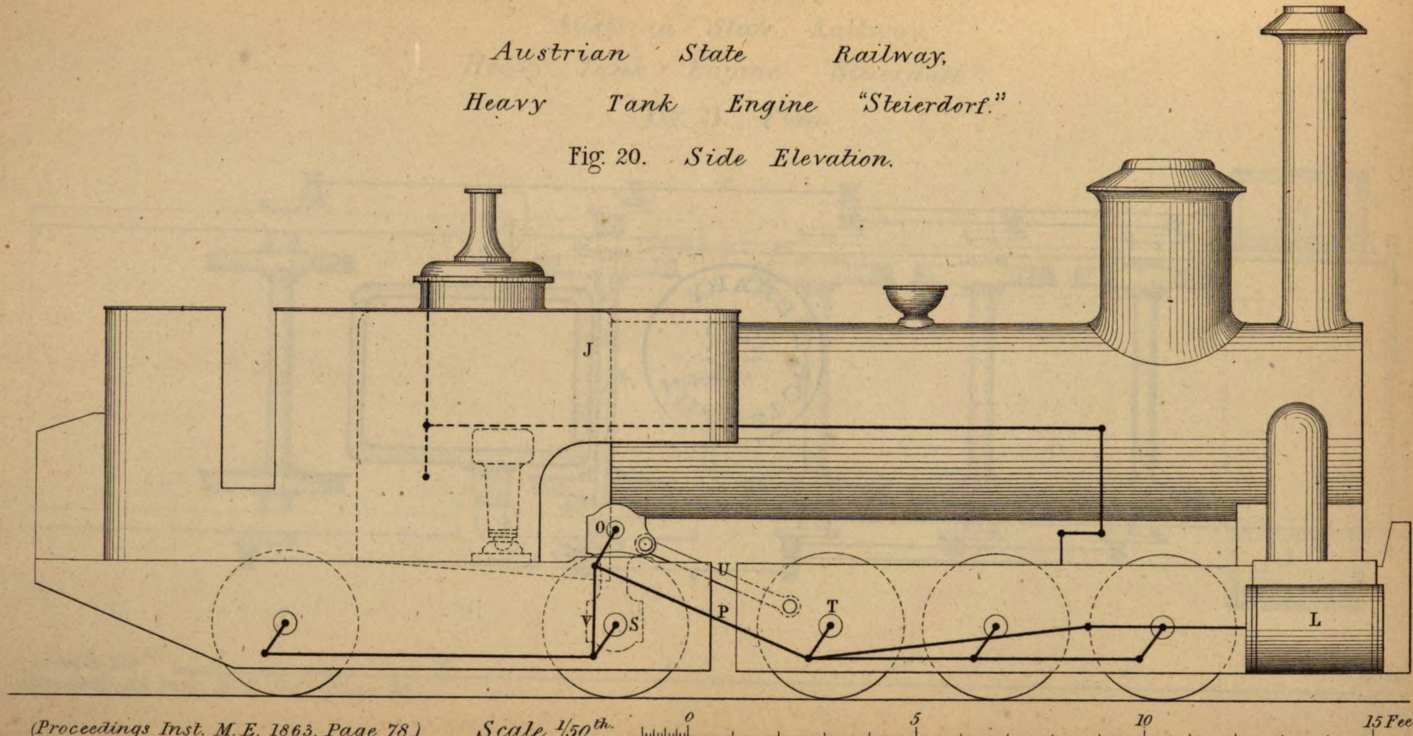
LOCOMOTIVES IN EXHIBITION 1862.

Plate 29.

Austrian State Railway,

Heavy Tank Engine "Steierdorf."

Fig. 20. *Side Elevation.*



Scale 1/50th.

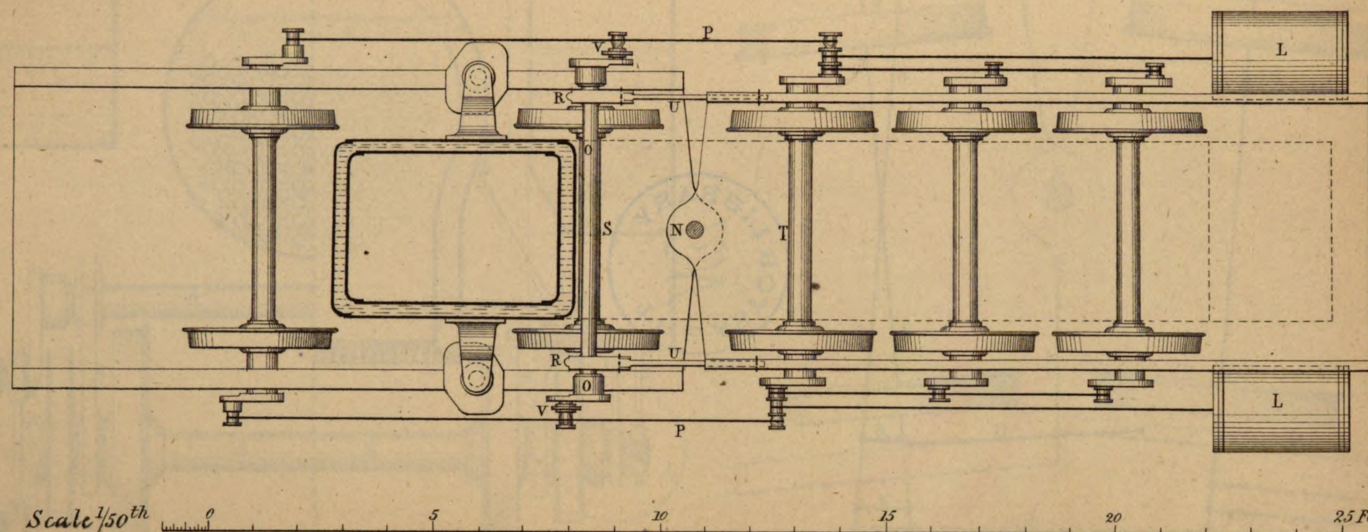
(Proceedings Inst. M. E. 1863. Page 78.)

LOCOMOTIVES IN EXHIBITION 1862.

Austrian State Railway,

Heavy Tank Engine "Steierdorf."

Fig. 21. *Plan.*



Scale 1/50th

(Proceedings Inst. M.E. 1863. Page 78.)

LOCOMOTIVES IN EXHIBITION 1862.

Plate 31.

Austrian State Railway, Heavy Tank Engine "Steierdorf."

Fig. 22. Transverse Section.

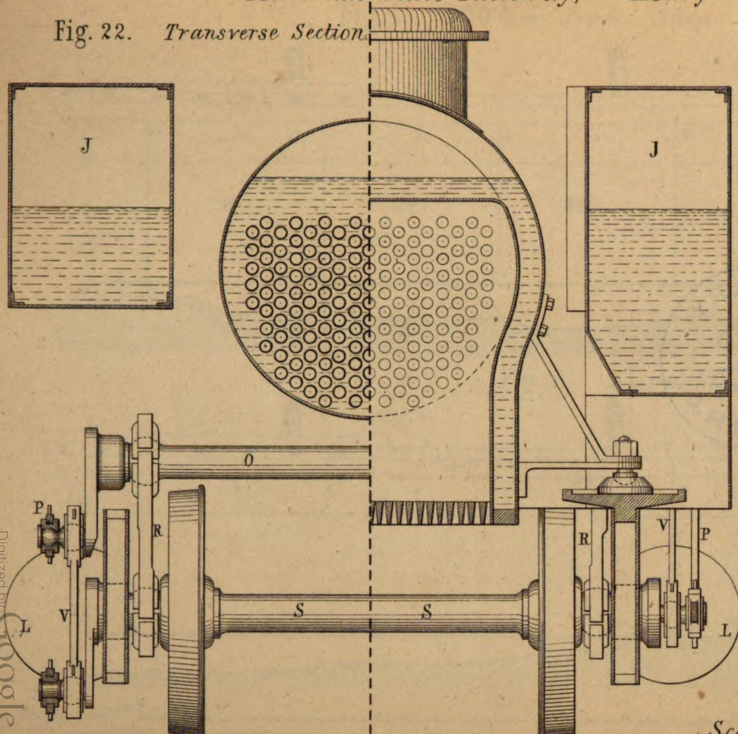
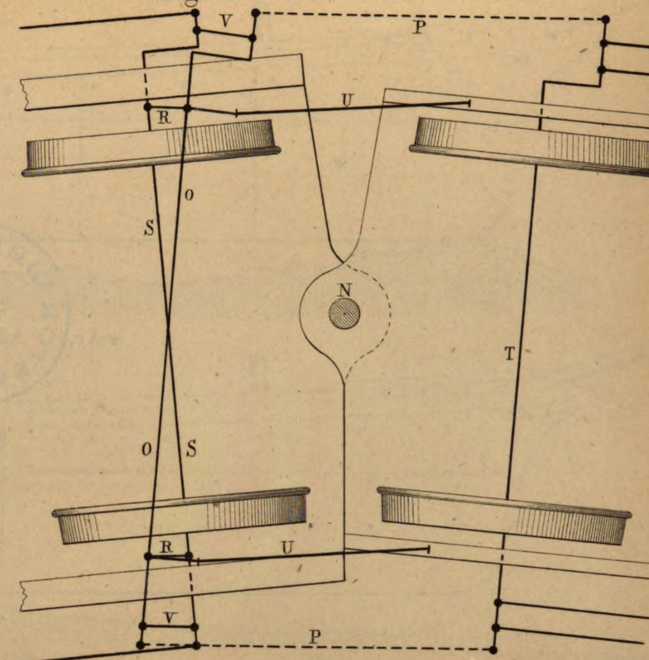


Fig. 23. Plan on curve.



Scale 1/30th.

0 5 10 Feet.

(Proceedings Inst. M.E. 1863. Page 78.)

CONSTRUCTION OF IRON SHIPS.

Fig. 1. 1200 ton Iron Ship supported at ends.

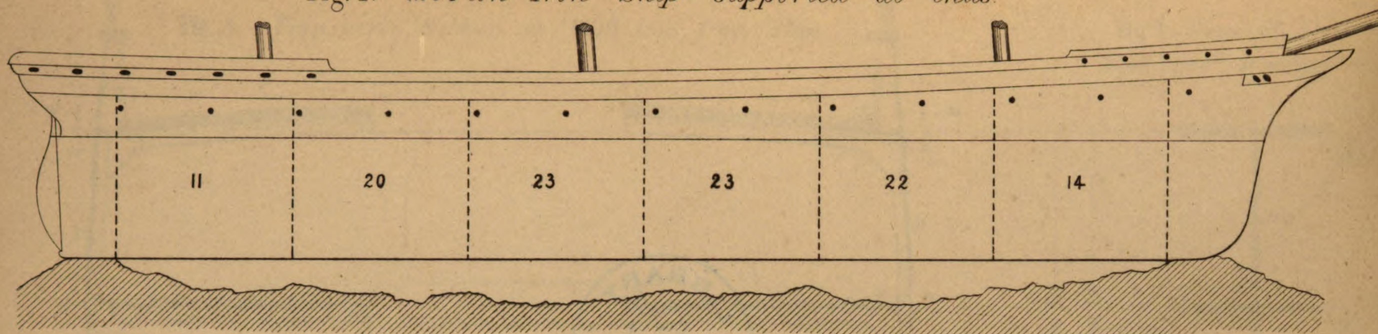
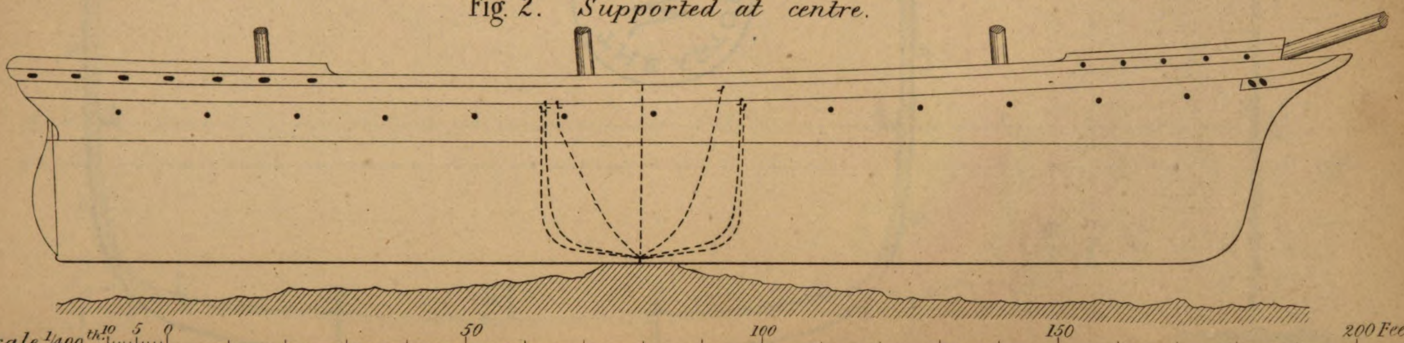


Fig. 2. Supported at centre.



(Proceedings Inst. M.E. 1863. Page 115.)

Fig. 3. *Transverse Section of 1200 ton Iron Ship.*

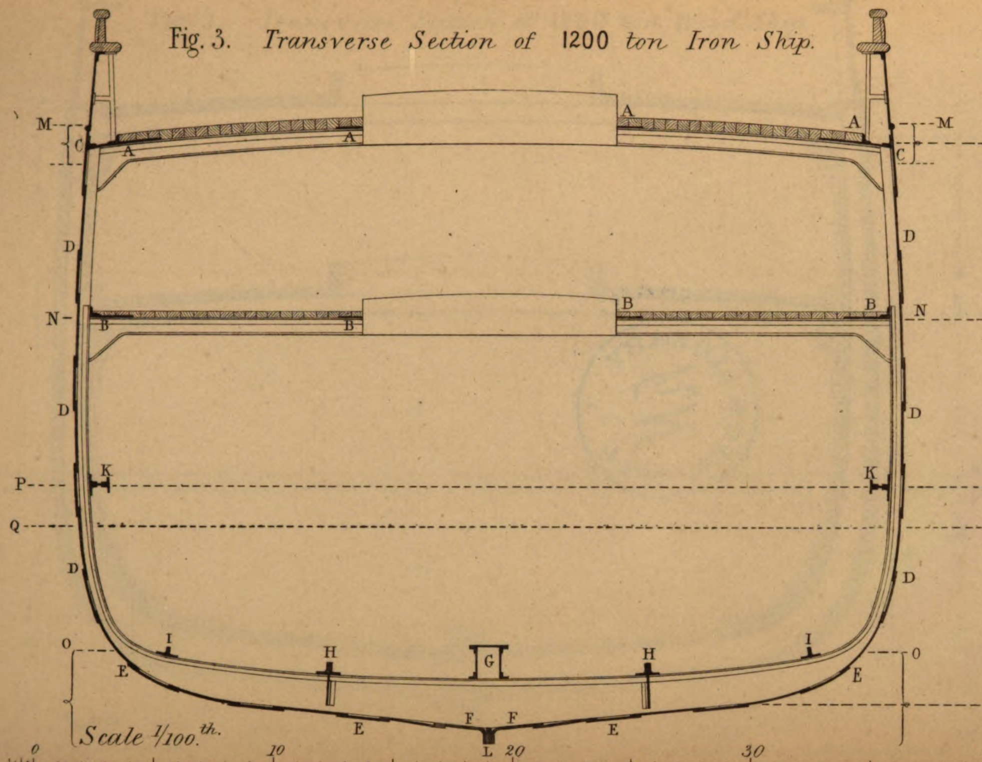
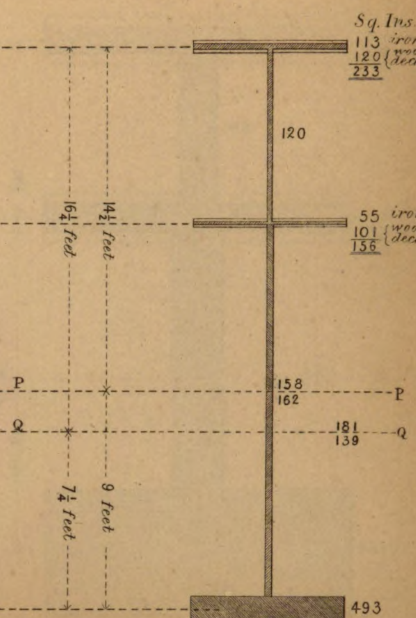


Fig. 4. *Area of Section.*
Scale 1/5000th. of actual area.

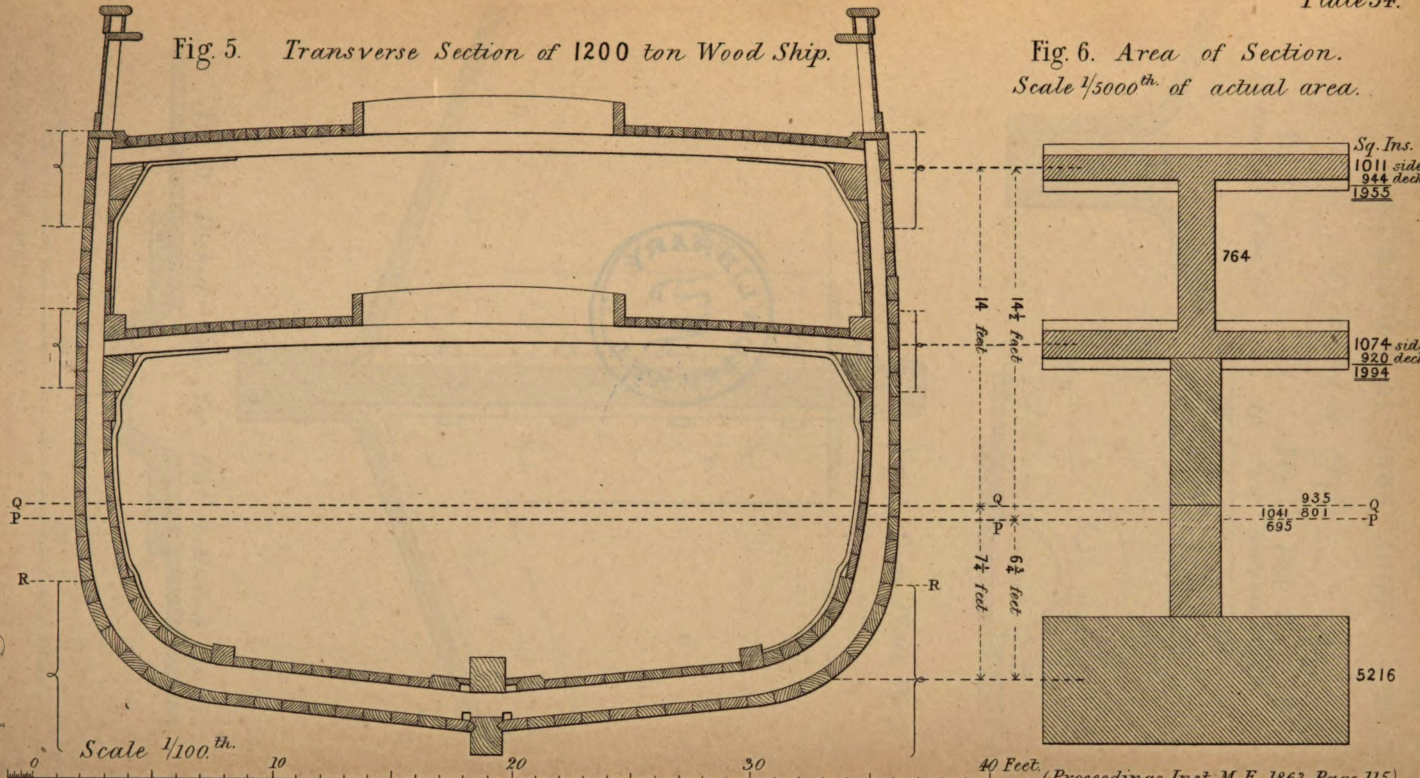


CONSTRUCTION OF IRON SHIPS.

Plate 34.

Fig. 5. *Transverse Section of 1200 ton Wood Ship.*

Fig. 6. *Area of Section.*
Scale 1/5000th. of actual area.



Scale 1/100th.

(*Proceedings Inst. M.E. 1863. Page 115.*)

CONSTRUCTION OF IRON SHIPS. *Plate 35.*

Sections of Keels.

Fig. 7.
Ordinary Keel.

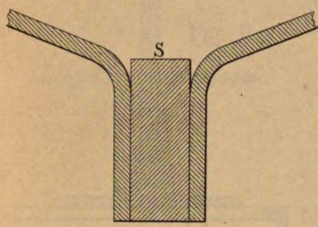


Fig. 8. *Flat Plate Keel for flat bottomed vessels.*

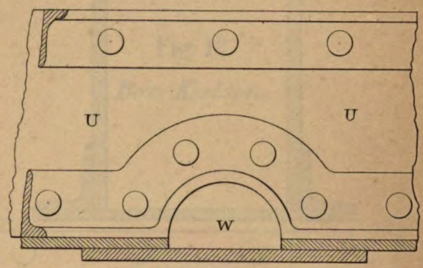


Fig. 9. *Deep Plate Keel.*

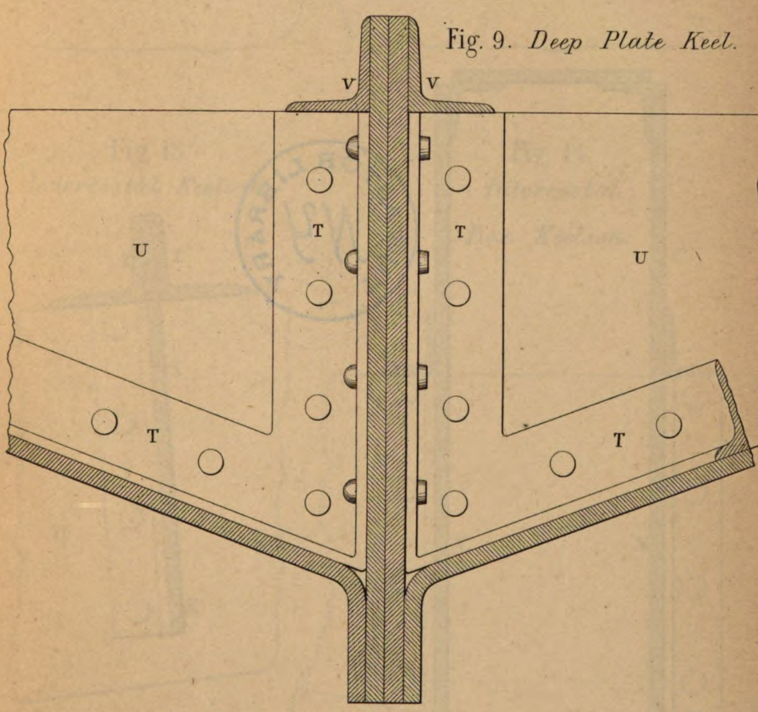
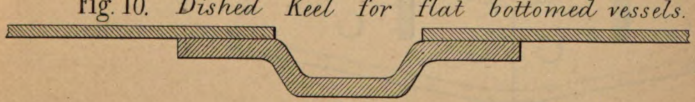


Fig. 10. *Dished Keel for flat bottomed vessels.*



Scale 1/10th. 0 10 20 30 *Inches.*

(Proceedings Inst. M.E. 1863. Page 115.)

Sections of Keelsons.

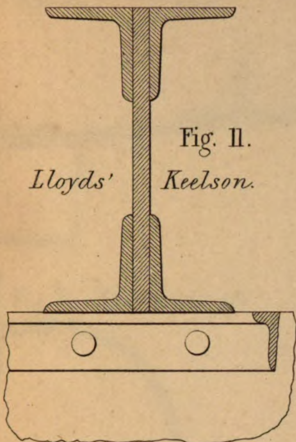


Fig. 11.
Lloyds' Keelson.

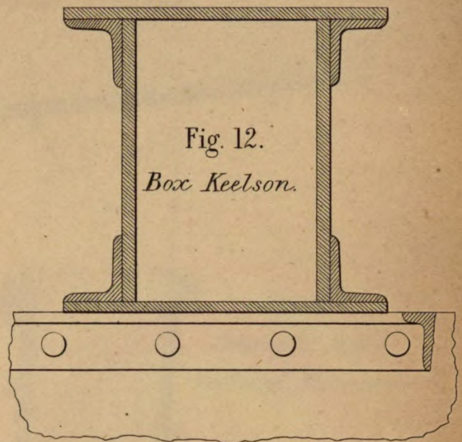
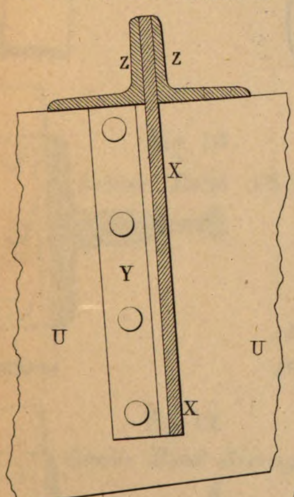


Fig. 12.
Box Keelson.

Fig. 13.
Intercostal Keelson.



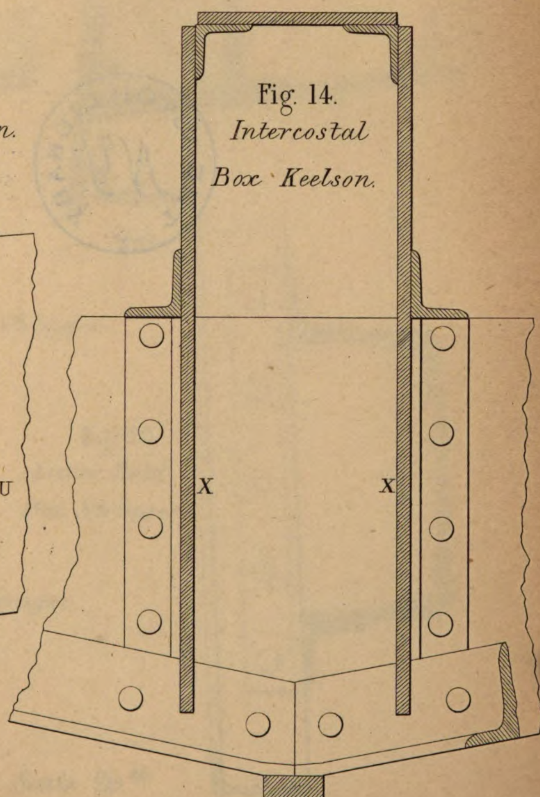


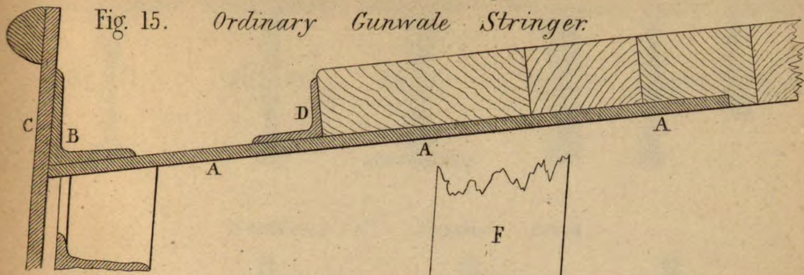
Fig. 14.
Intercostal Box Keelson.

(Proceedings Inst. M.E. 1863. Page 115.)

Scale 1/10th. 0 10 20 *30 Inches.*

Sections of Stringers.

Fig. 15. *Ordinary Gunwale Stringer.*



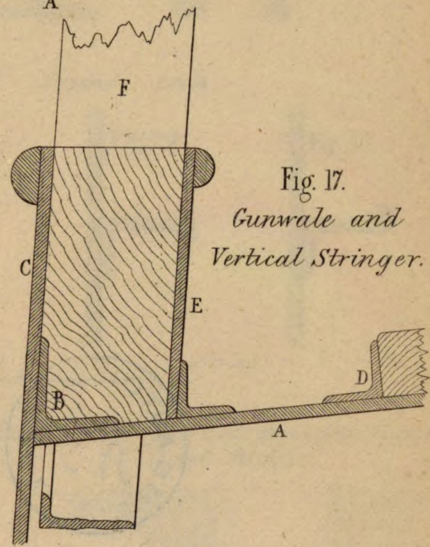


Fig. 17. *Gunwale and Vertical Stringer.*

Fig. 16. *Box Gunwale.*

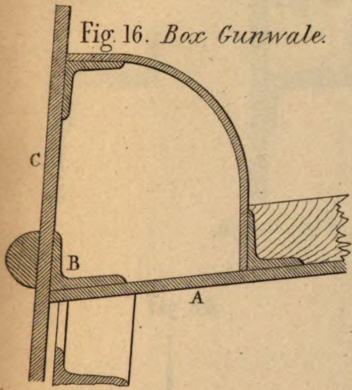


Fig. 18. *Lower Hold Stringer.*

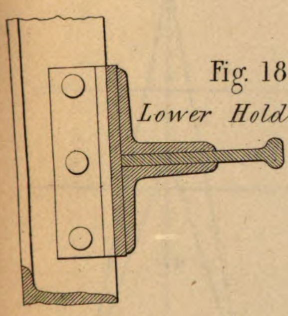


Fig. 20. *Lower Hold Box Stringer.*

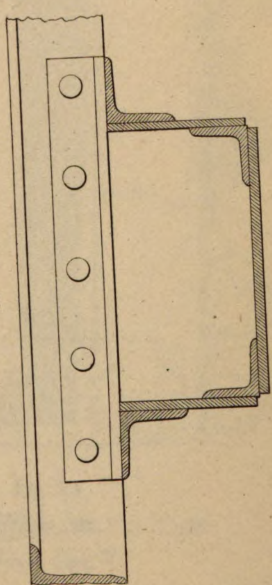
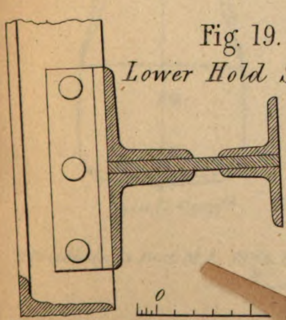


Fig. 19. *Lower Hold Stringer.*



Scale 1/10th.

0 10 20 30 *Inches.*

(Proceedings Inst. M.E. 1863. P... 115)

Sections of Deck Beams.

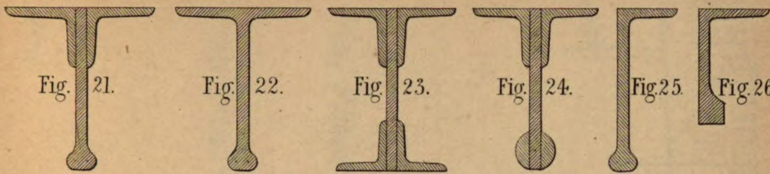


Fig. 21. Fig. 22. Fig. 23. Fig. 24. Fig. 25. Fig. 26.

Sections of Frame Iron.

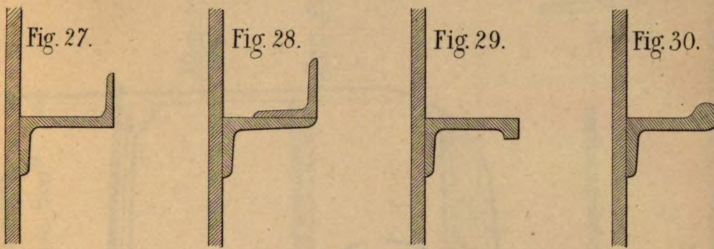


Fig. 27. Fig. 28. Fig. 29. Fig. 30.

Scale 1/10th.

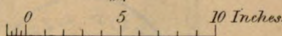
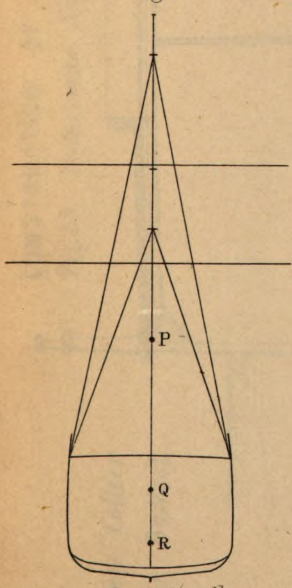


Fig. 34.



Scale 1/500th.

Fig. 31. *Stern Post and Screw Port Frame of "Great Britain."*

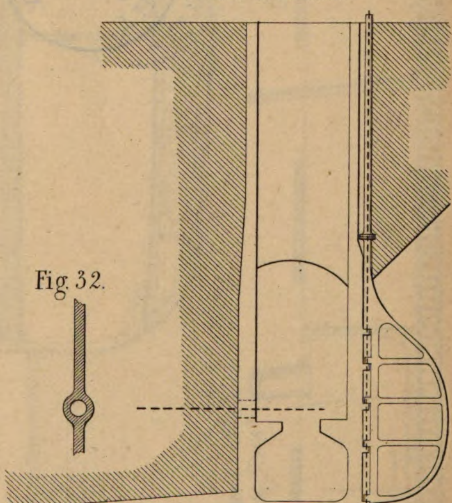
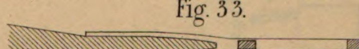


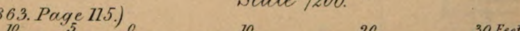
Fig. 32.

Fig. 33.

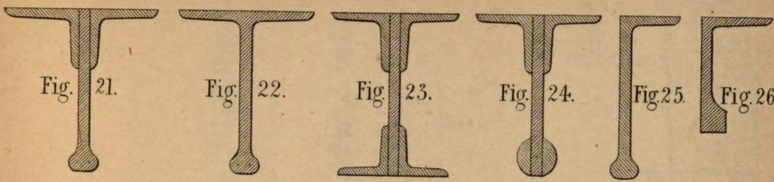


Scale 1/200th.

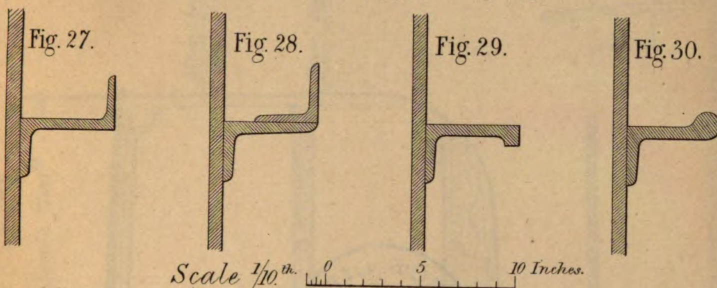
(Proceedings Inst. M. E. 1863. Page 115.)



Sections of Deck Beams.

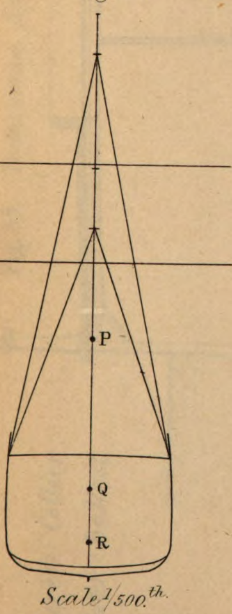


Sections of Frame Iron.



Scale 1/10th.

Fig. 34.



Scale 1/500th.

Fig. 31. *Stern Post and Screw Port Frame of "Great Britain".*

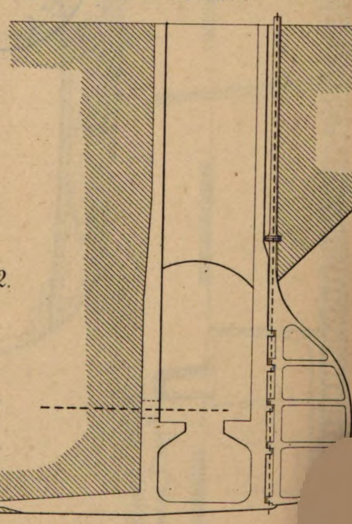


Fig. 32.

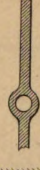
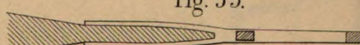
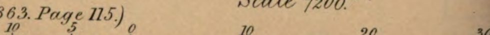


Fig. 33.

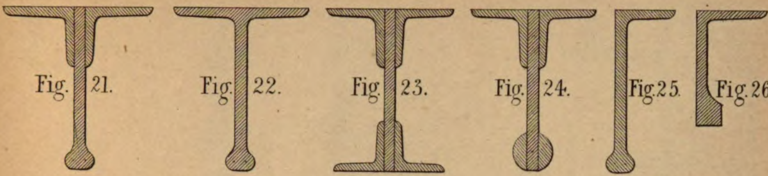


Scale 1/200th.

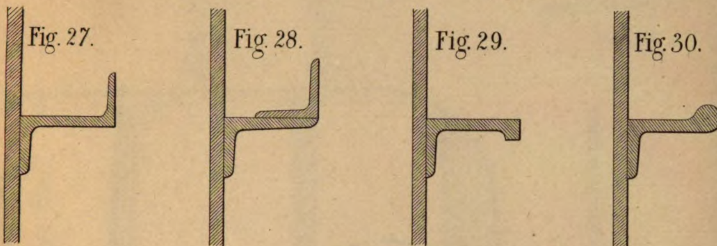
(Proceedings Inst. M.E. 1863. Page 115.)



Sections of Deck Beams.



Sections of Frame Iron.



Scale 1/10th.

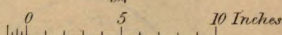
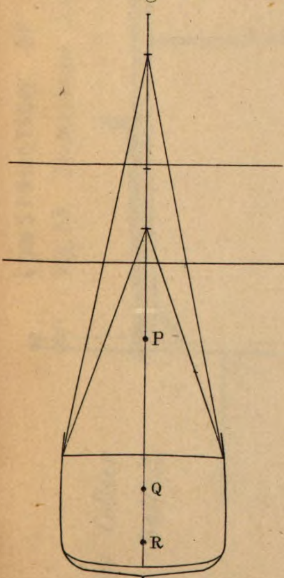


Fig. 34.



Scale 1/500th.

Fig. 31. *Stern Post and Screw Port Frame of "Great Britain".*

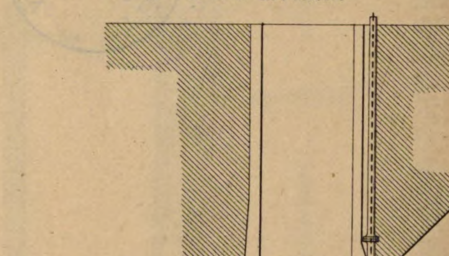
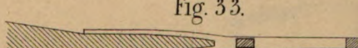


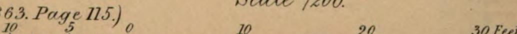
Fig. 32.

Fig. 33.



Scale 1/200th.

(Proceedings Inst. M. E. 1863. Page 115.)



CONSTRUCTION OF IRON SHIPS.

Iron Screw Collier with Water Ballast.

Fig. 35. Transverse Section. Scale 1/100th.

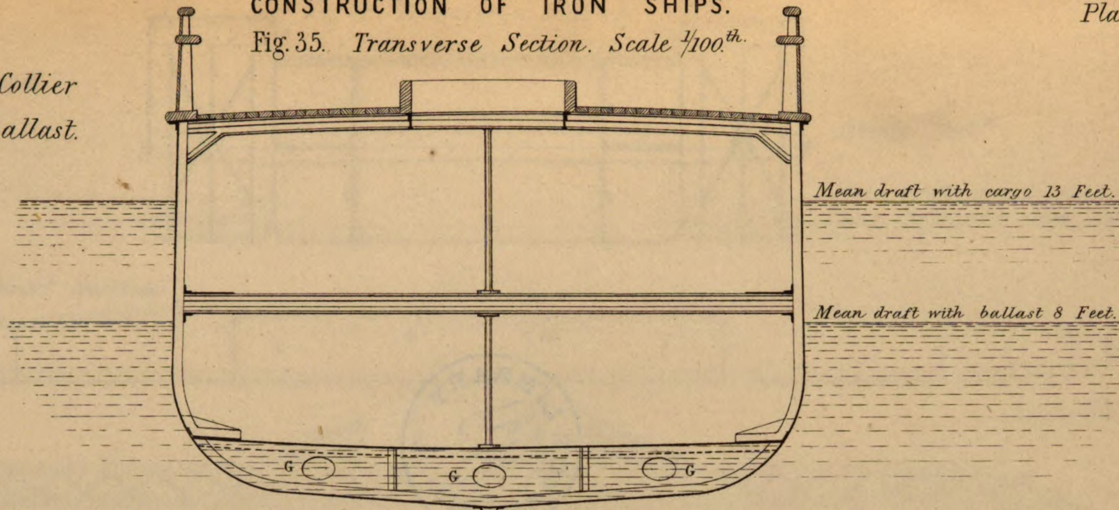
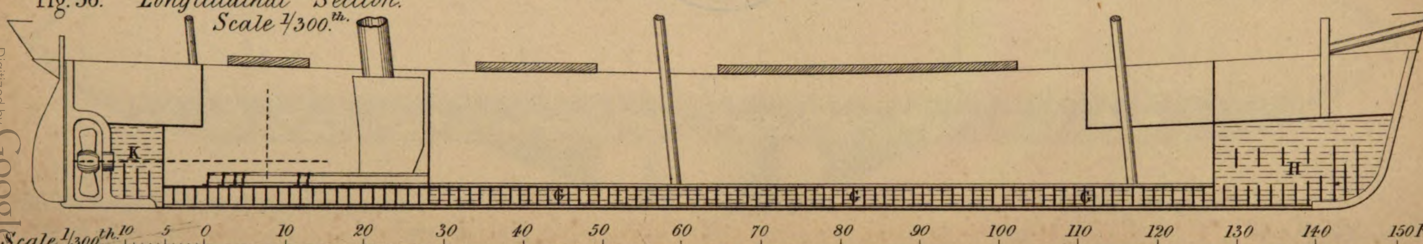


Fig. 36. Longitudinal Section. Scale 1/300th.



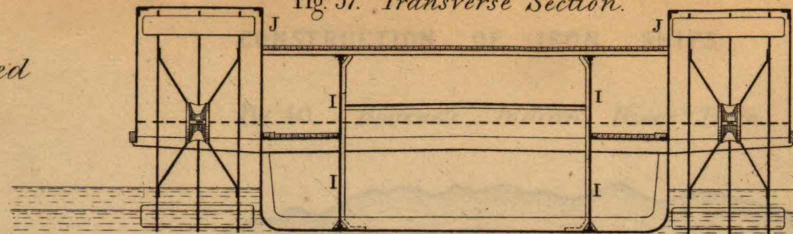
(Proceedings Inst. M.E. 1863. Page 115.)

CONSTRUCTION OF IRON SHIPS.

Plate 40.

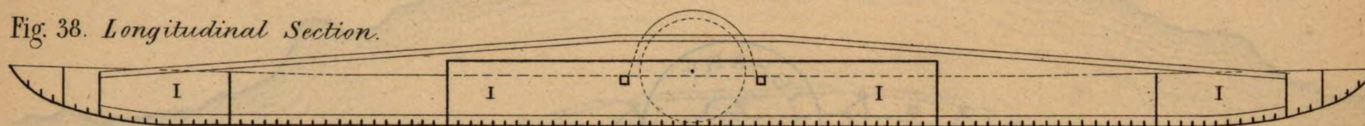
Flat Bottomed River Boat.

Fig. 37. *Transverse Section.*



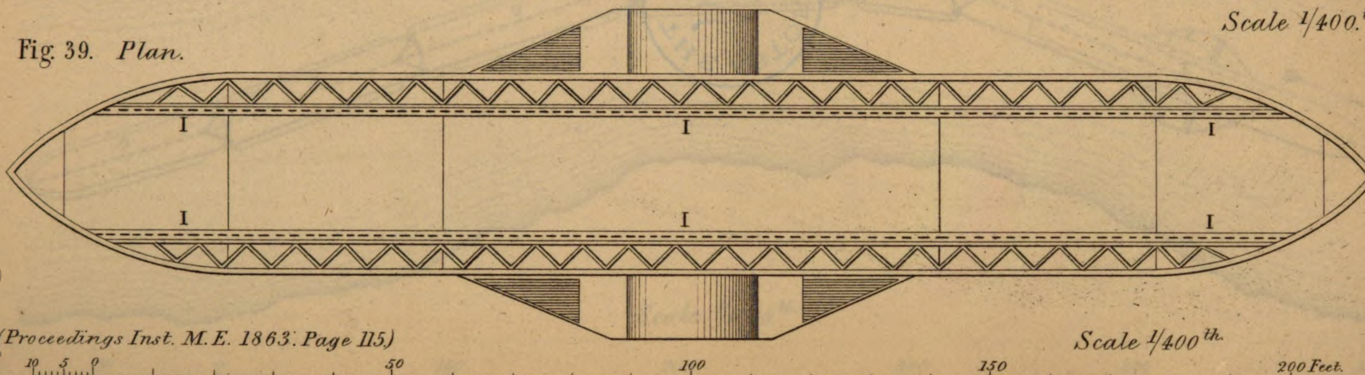
Scale 1/200th.

Fig. 38. *Longitudinal Section.*



Scale 1/400th.

Fig. 39. *Plan.*



Scale 1/400th.

(Proceedings Inst. M.E. 1863. Page 115.)

Fig. 40. *Bourne's Indian River Train.*

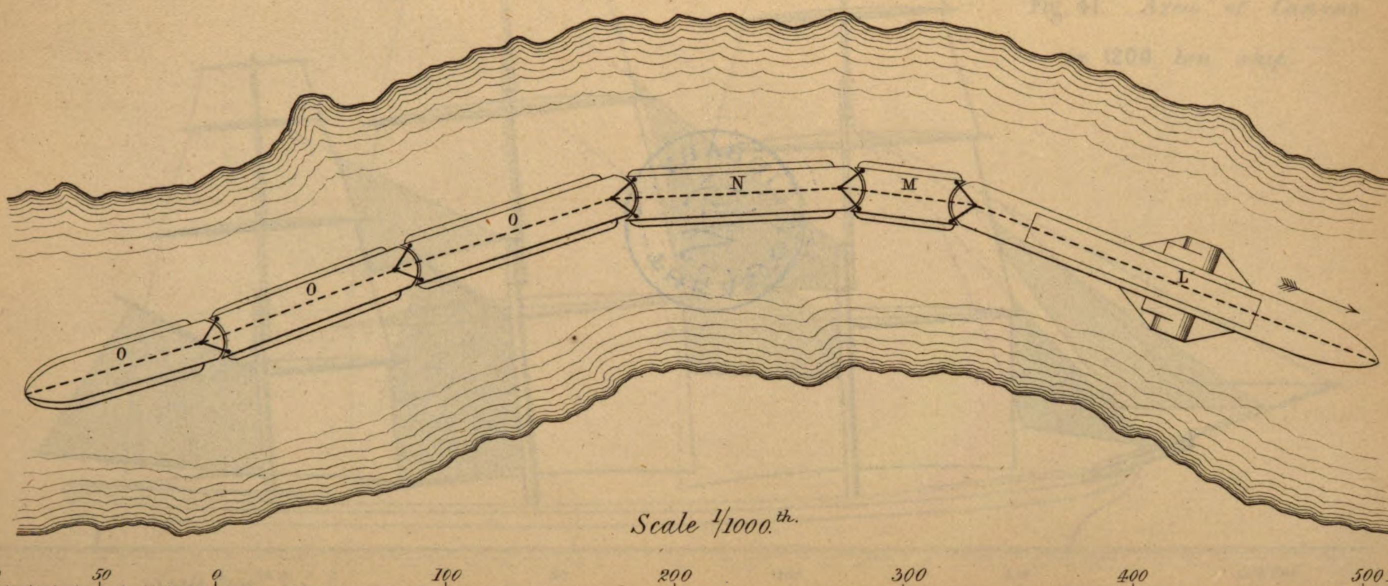
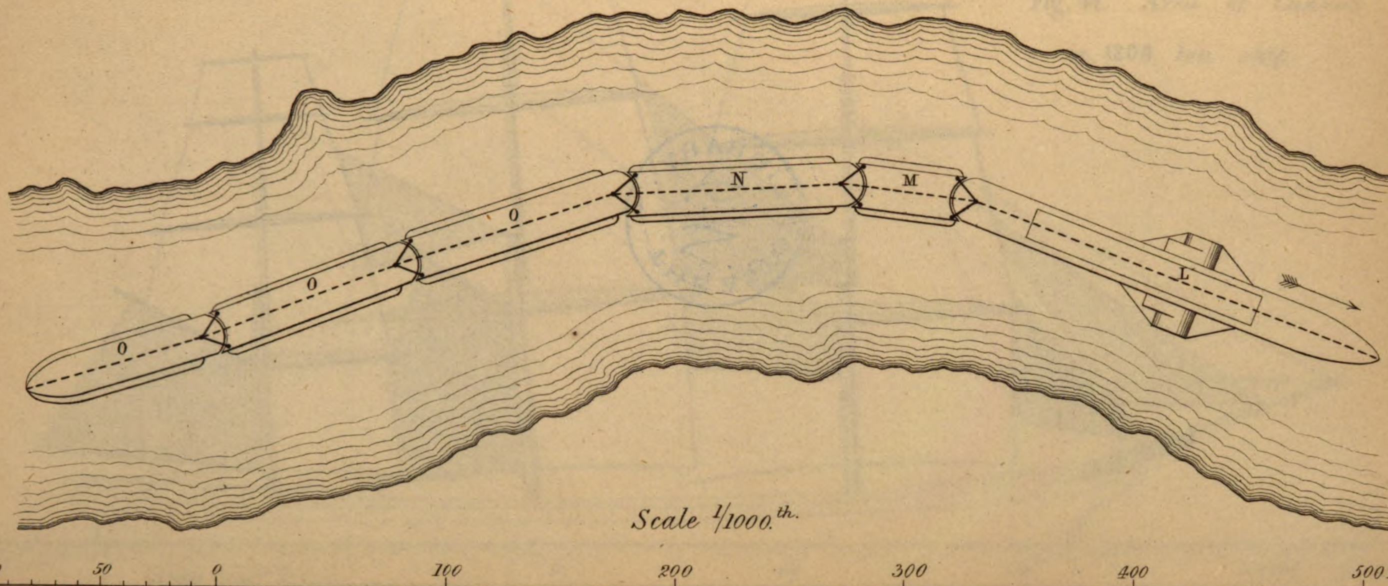


Fig. 40. *Bourne's Indian River Train.*



Sections of Stringers.

Fig. 15. *Ordinary Gunwale Stringer.*

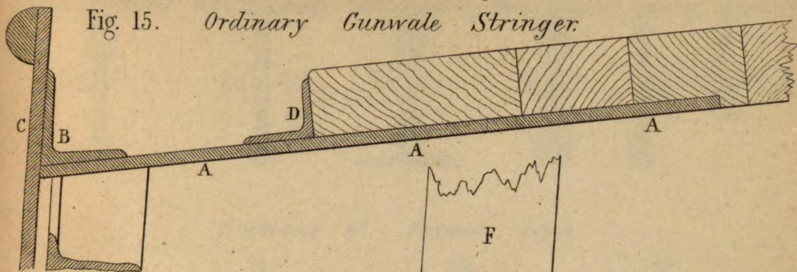
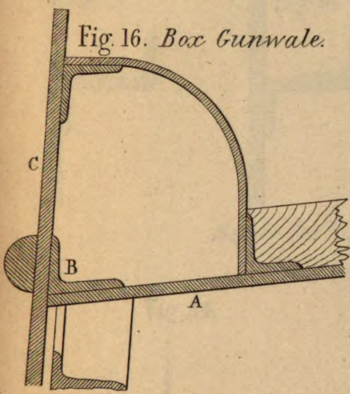


Fig. 16. *Box Gunwale.*



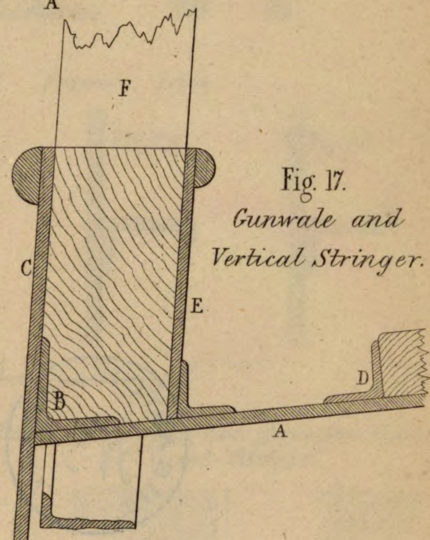


Fig. 17. *Gunwale and Vertical Stringer.*

Fig. 18. *Lower Hold Stringer.*

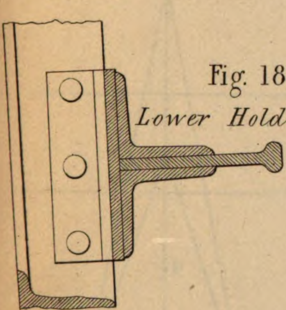


Fig. 20. *Lower Hold Box Stringer.*

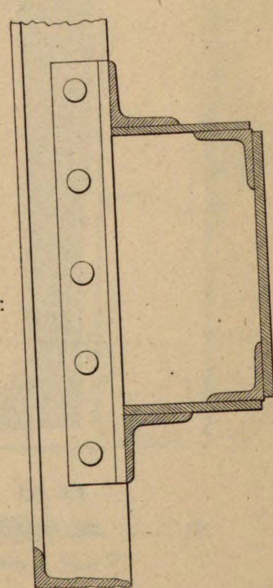
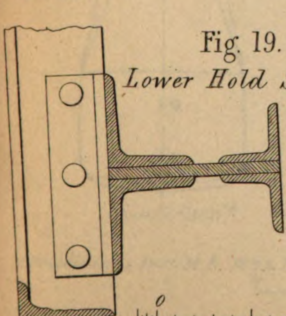
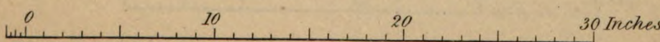


Fig. 19. *Lower Hold Stringer.*

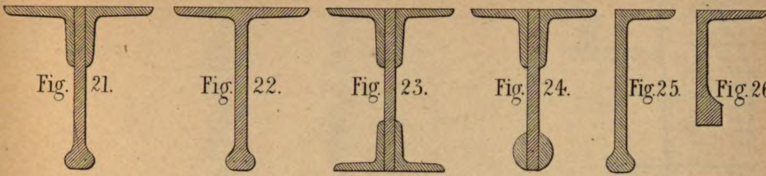


Scale 1/10.th

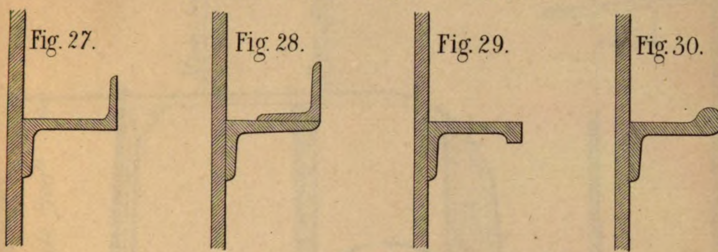


(Proceedings Inst. M.E. 1863. Page 115.)

Sections of Deck Beams.

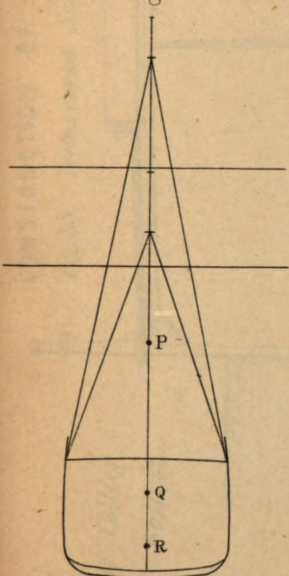


Sections of Frame Iron.



Scale 1/10th. 0 5 10 *Inches.*

Fig. 34.



Scale 1/500th.

Fig. 31. *Stern Post and Screw Port Frame of "Great Britain".*

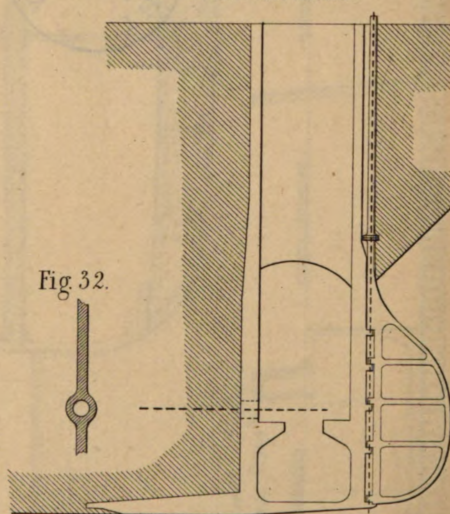
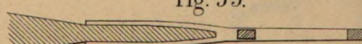


Fig. 33.



Scale 1/200th.

(Proceedings Inst. M. E. 1863. Page 115.)

10 5 0 10 20 30 *Feet.*

Plate 39.

CONSTRUCTION OF IRON SHIPS.

Iron Screw Collier
with Water Ballast.

Fig. 35. *Transverse Section. Scale 1/100th.*

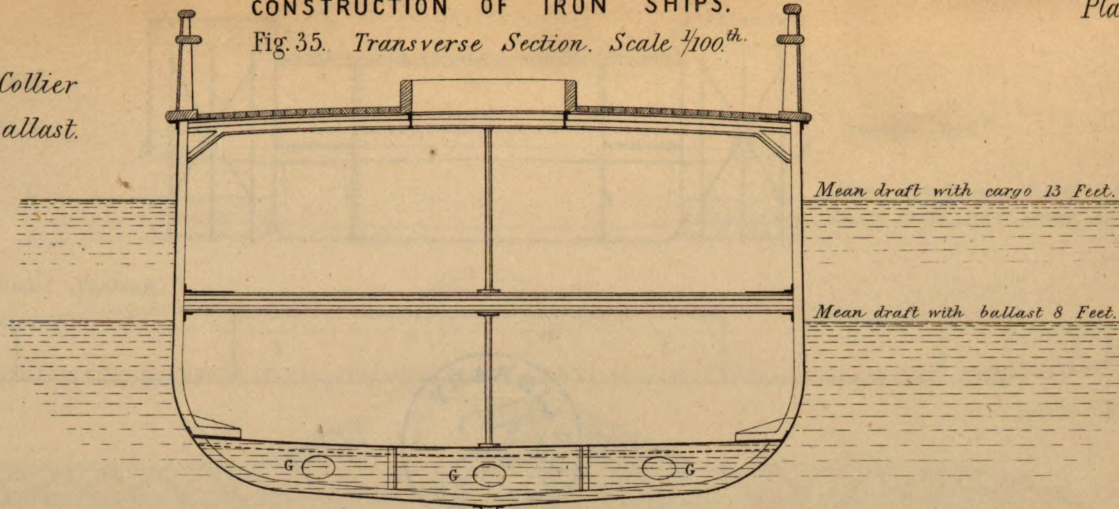
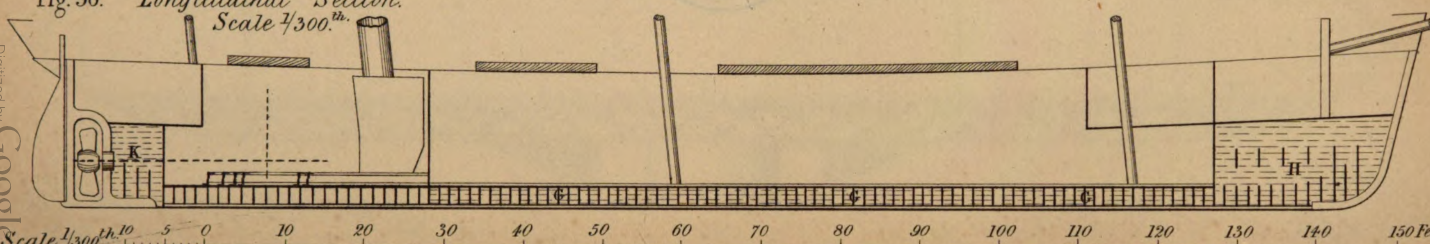


Fig. 36. *Longitudinal Section. Scale 1/300th.*



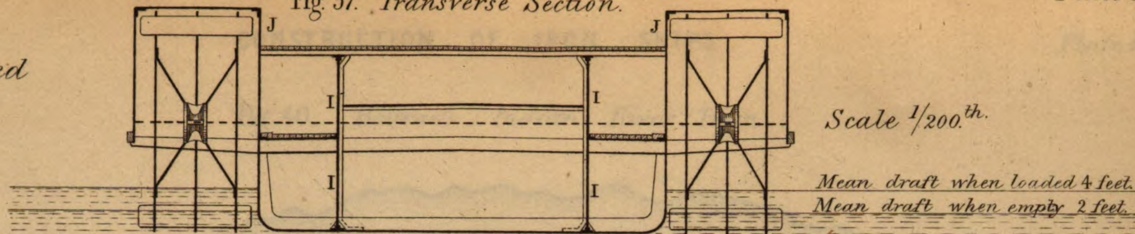
(Proceedings Inst. M.E. 1863. Page 115.)

CONSTRUCTION OF IRON SHIPS.

Plate 40.

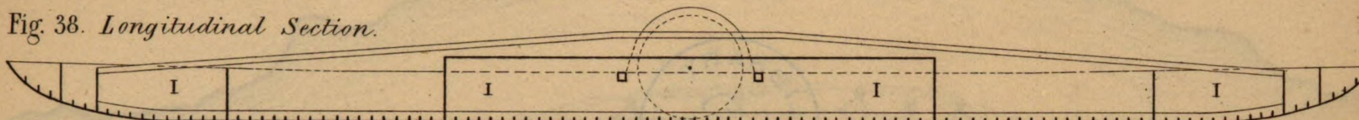
Flat Bottomed River Boat.

Fig. 37. Transverse Section.



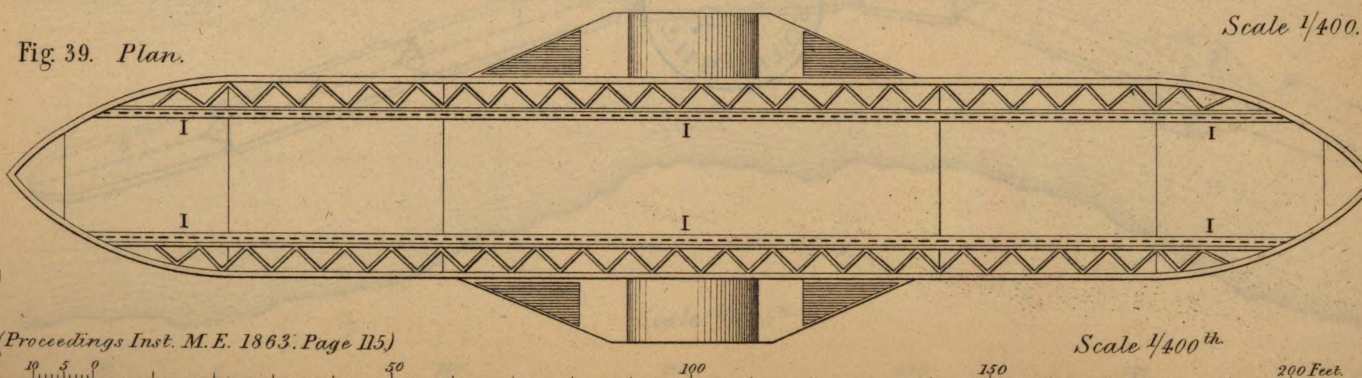
Scale 1/200th.

Fig. 38. Longitudinal Section.



Scale 1/400th.

Fig. 39. Plan.



Scale 1/400th.

Fig. 40. *Bourne's Indian River Train.*

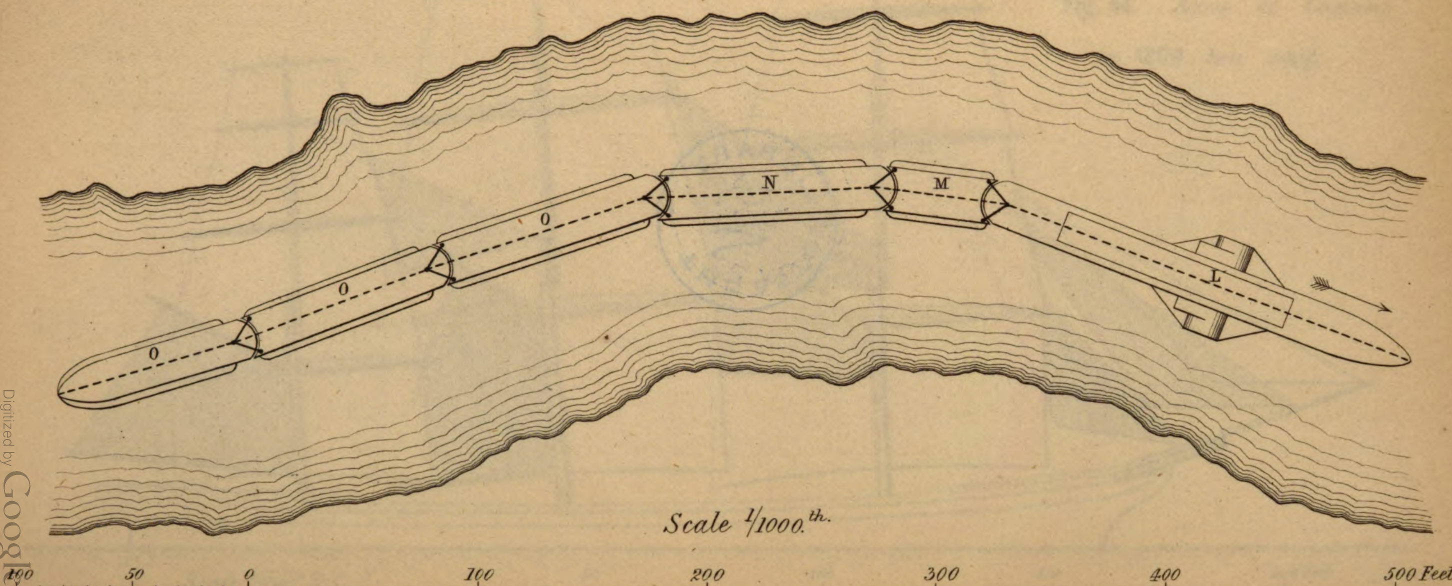
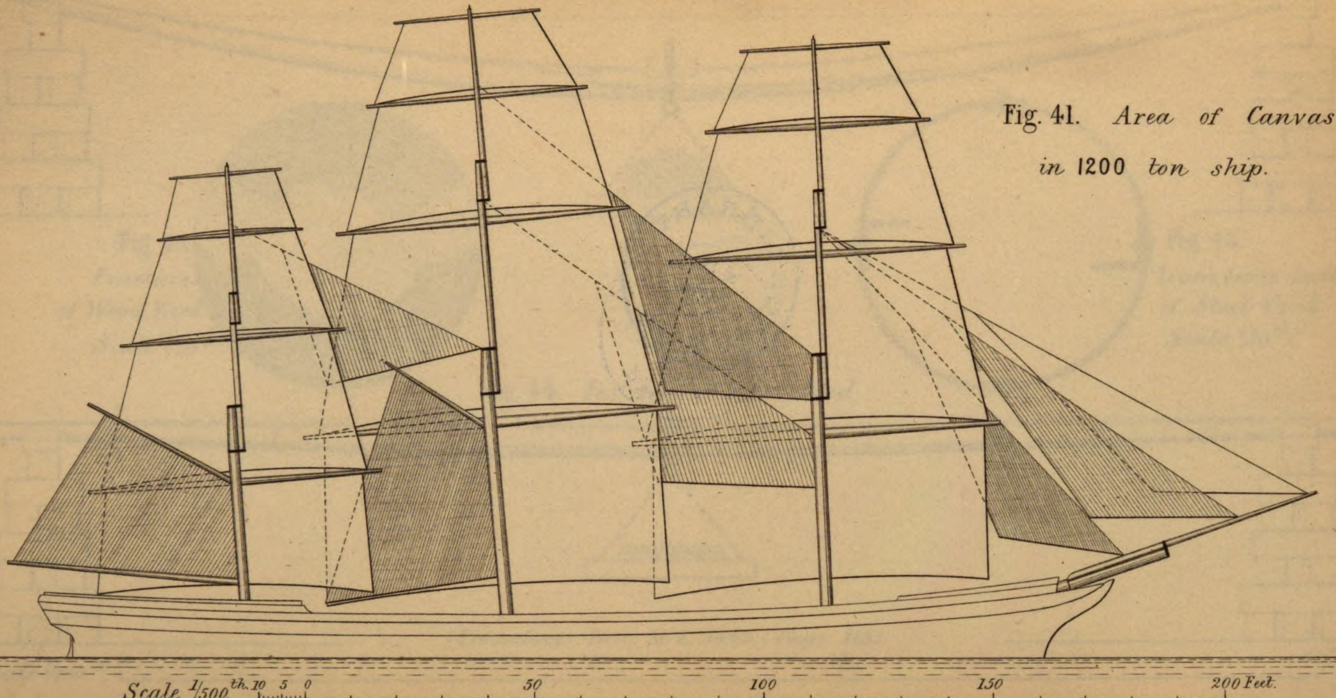


Fig. 41. *Area of Canvas in 1200 ton ship.*

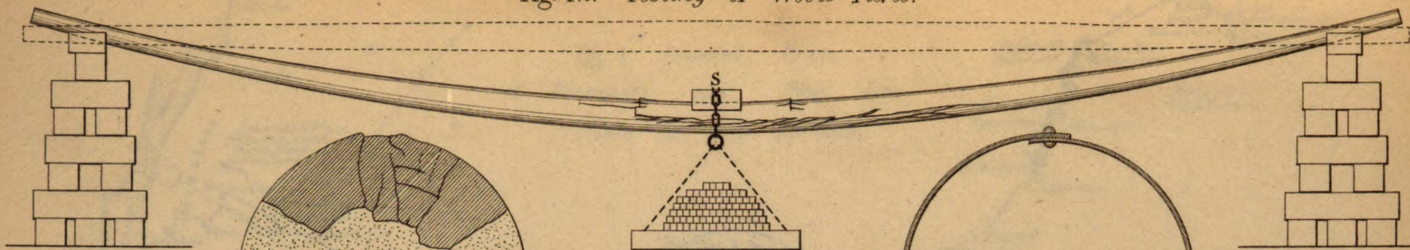


(*Proceedings Inst. M.E. 1863. Page 115.*)

CONSTRUCTION OF IRON SHIPS.

Plate 43.

Fig. 42. *Testing of Wood Yard.*



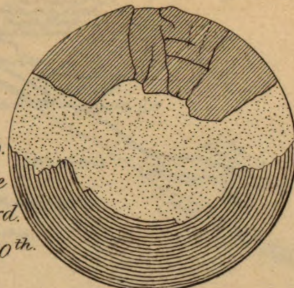


Fig. 43. *Fracture of Wood Yard. Scale 1/10th.*

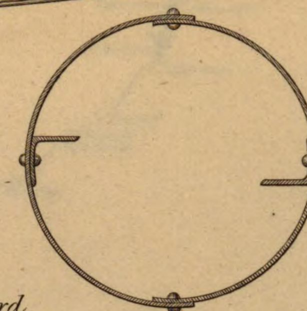
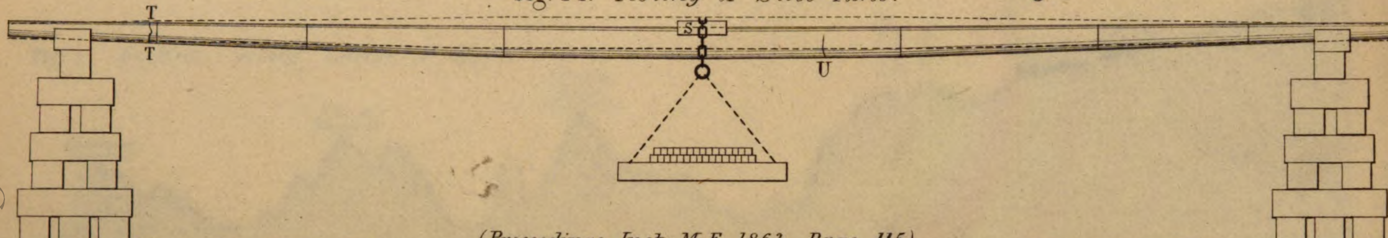
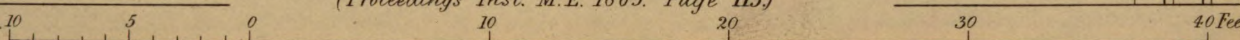


Fig. 45. *Transverse Section of Steel Yard. Scale 1/10th.*

Fig. 44. *Testing of Steel Yard.*



(Proceedings Inst. M.E. 1863. Page 115.)



Scale 1/100th.

LIVERPOOL WATER WORKS.

Plate 44.

Fig. 1. *General Plan of Reservoirs and Pipe Line.*

Scale 1/5th inch per mile.

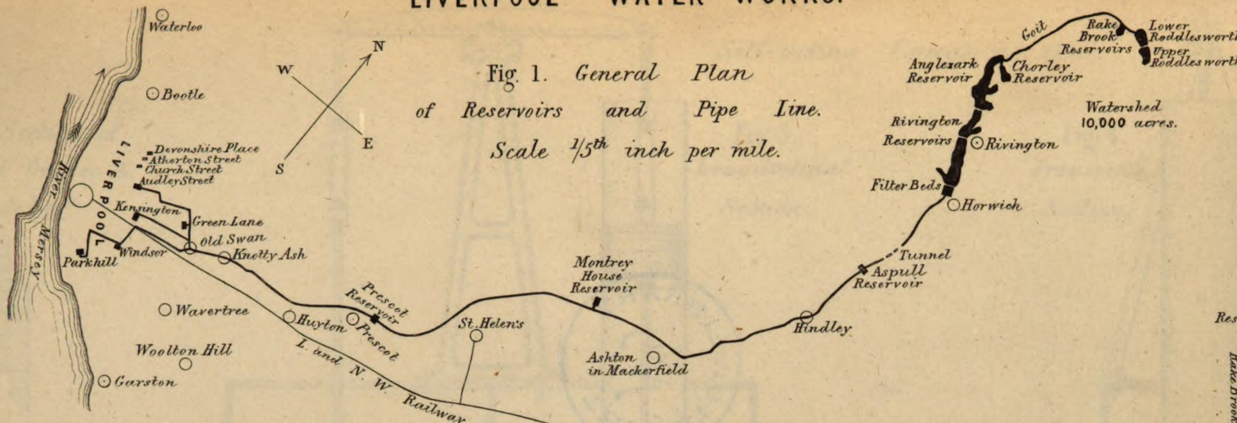
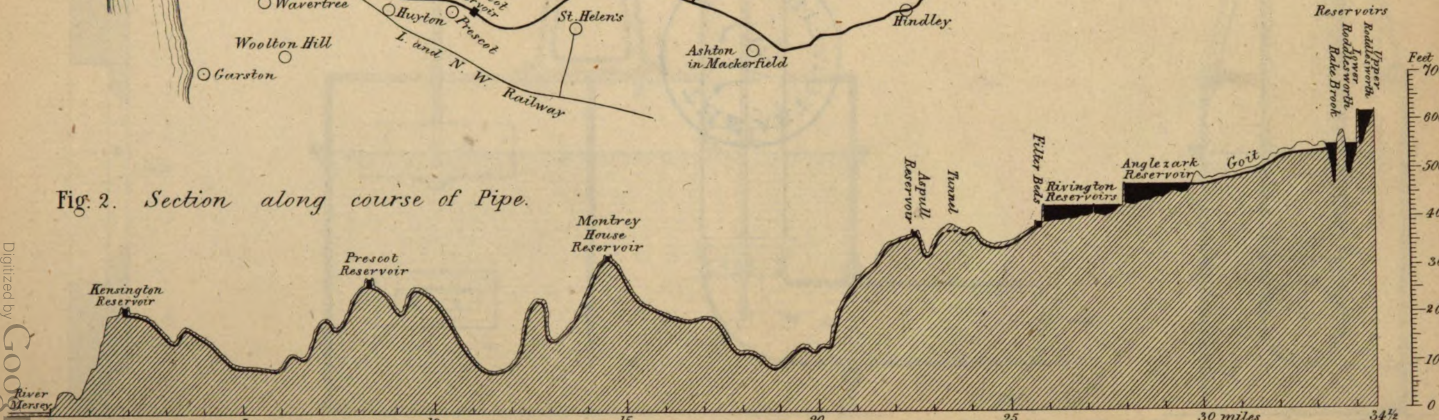


Fig. 2. *Section along course of Pipe.*



(Proceedings Inst. M.E. 1863. Page 167.)

Horizontal Scale 1/5th inch per mile.

LIVERPOOL WATER WORKS.

Plate 45.

Self-acting Gauge on Goit.

Fig. 5. Section of Outlet Orifice B.
Scale 1/4th.

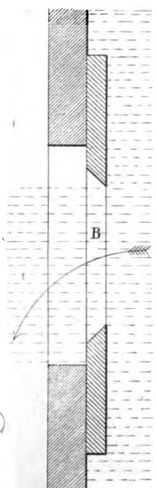


Fig. 3. Longitudinal Section.

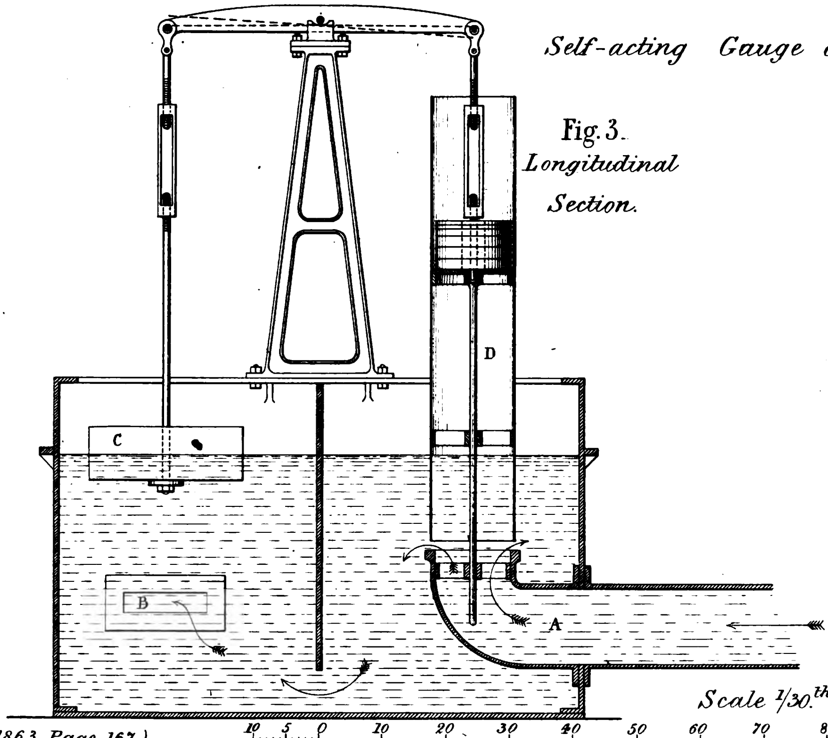
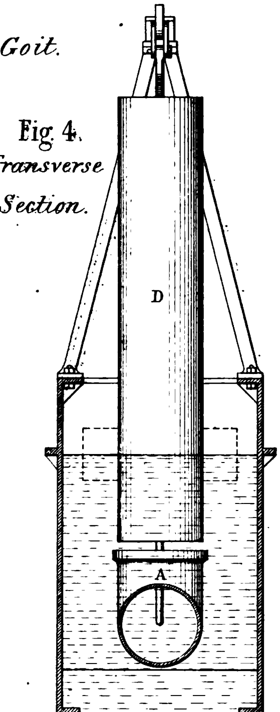


Fig. 4. Transverse Section.



Scale 1/30th.

(Proceedings Inst. M.E. 1863. Page 167.)

Float Valve at upper end of tunnel.

Fig. 6. *Vertical Section.*

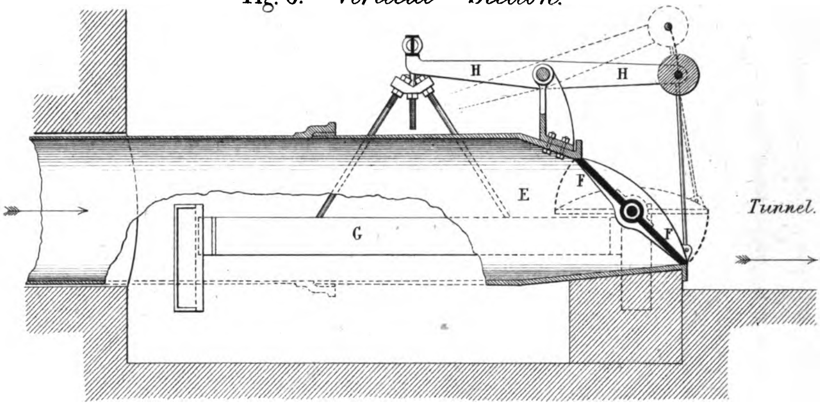
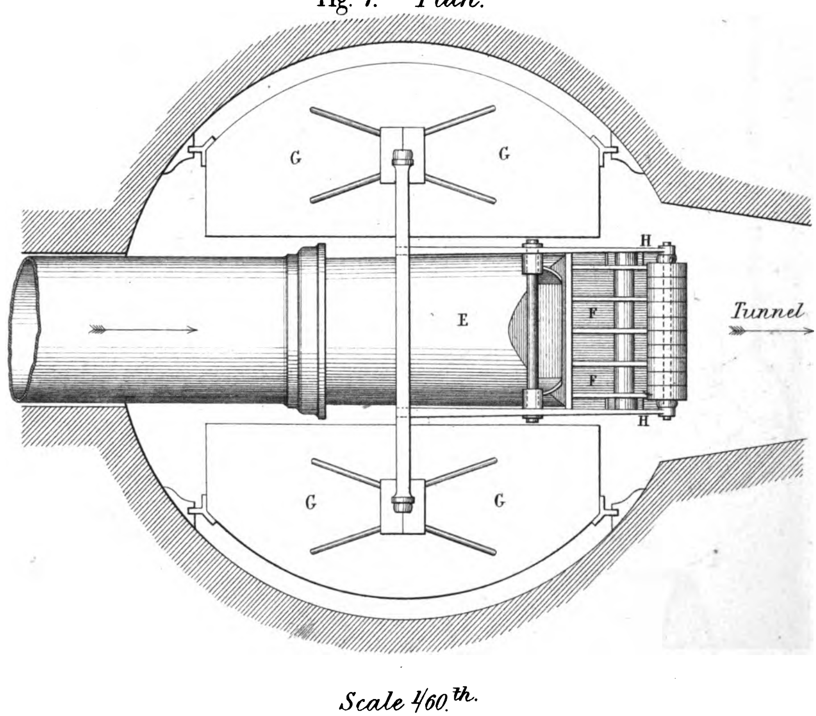


Fig. 7. *Plan.*



Scale 1/60th.

0 5 10 15 Feet.

LIVERPOOL WATER WORKS. *Plate 47.*

Self-acting Shut-Off Valve.

Fig. 8. *Vertical Section.*

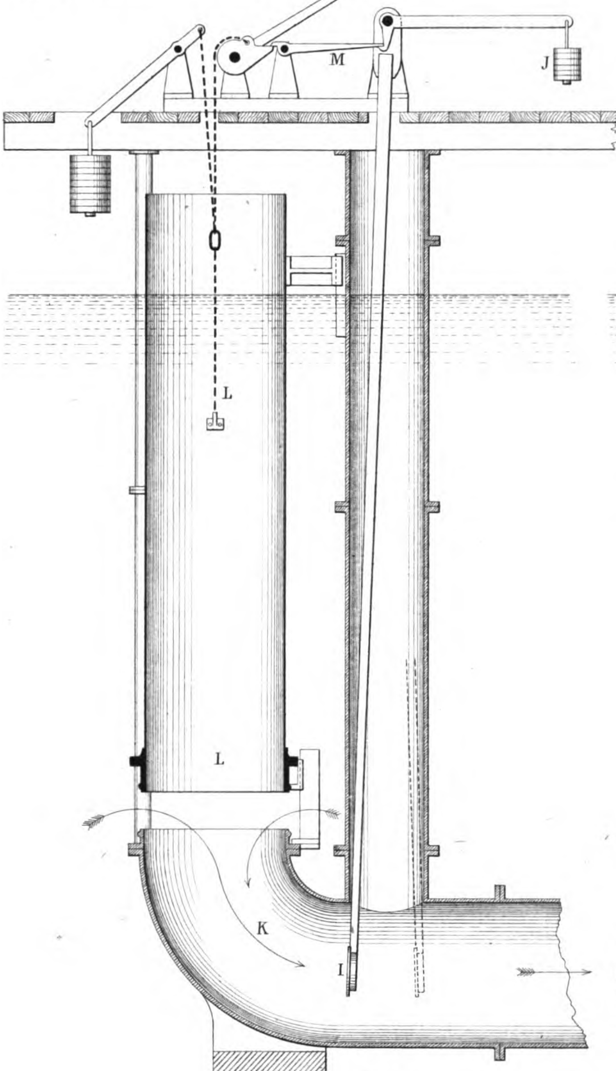


Fig. 9.

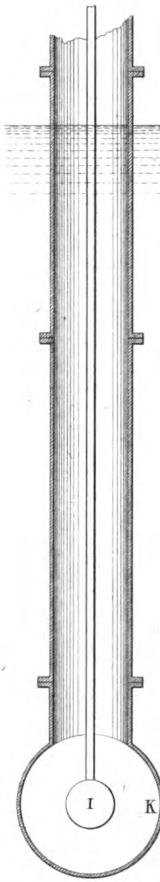
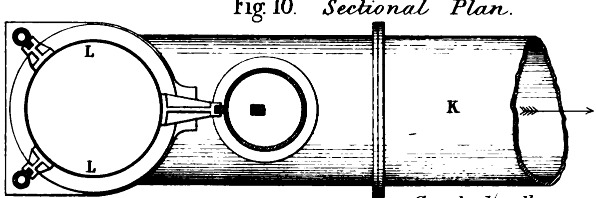


Fig. 10. *Sectional Plan.*



(Proceedings Inst. M.E. 1863. Page 167.)

Scale 1/60th.

0 5 10 15 Feet.

LIVERPOOL WATER WORKS. *Plate 48.*

Fig. 11. *Elevation of Reflux Valve.*

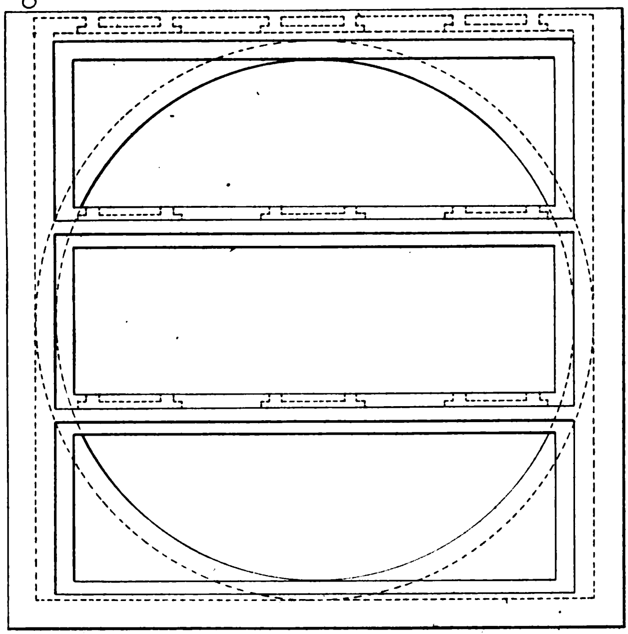


Fig. 12. *Vertical Section.*

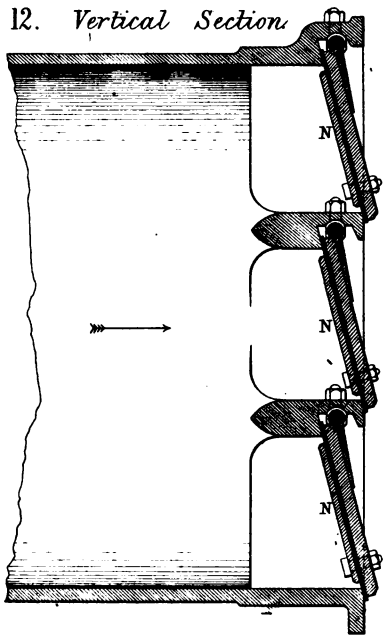
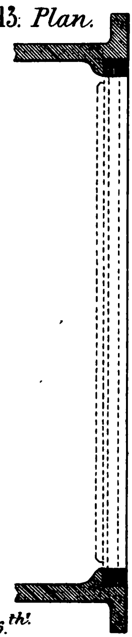


Fig. 13. *Plan.*



Scale 1/16th.

0 5 10 15 20 25 30 *Inches.*

(Proceedings Inst. M. E. 1863. Page 167.)

LIVERPOOL WATER WORKS. *Plate 49.*

Self-acting Throttle Valve in Main.

Fig. 14. *Side Elevation.*

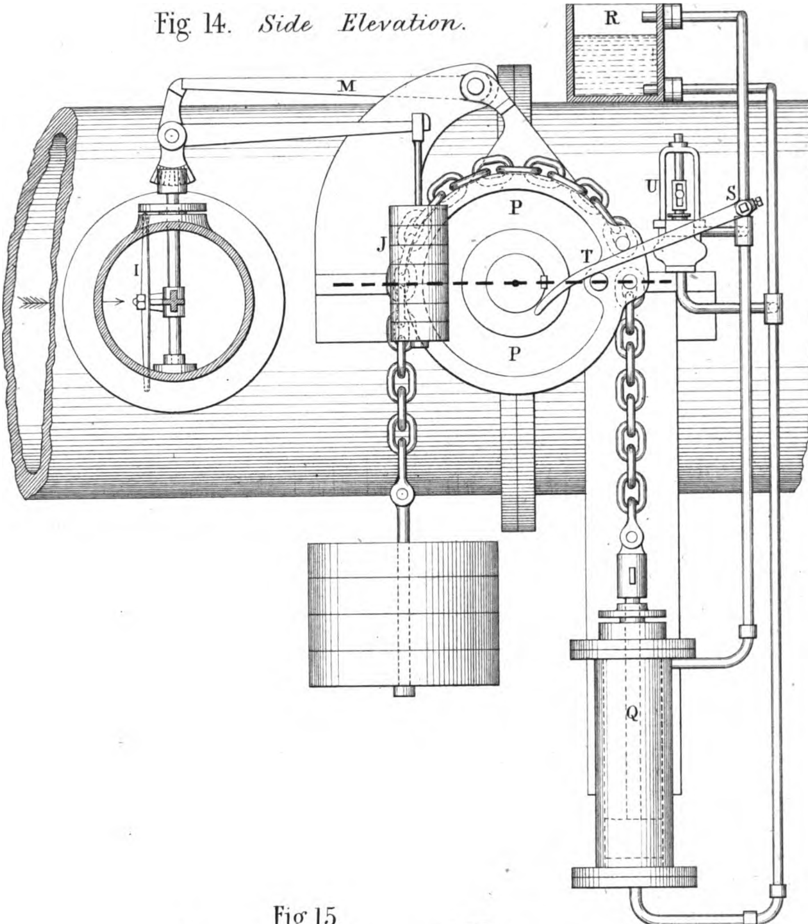
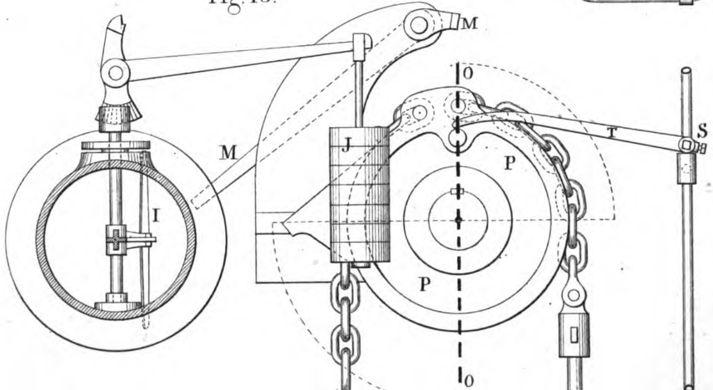


Fig. 15.



(Proceedings Inst. M. E. 1863. Page 167.)

Scale 1/20th 10 5 0 10 20 30 40 50 *Inches.*

Self-acting Throttle Valve in Main.

Fig. 16. *Plan.*

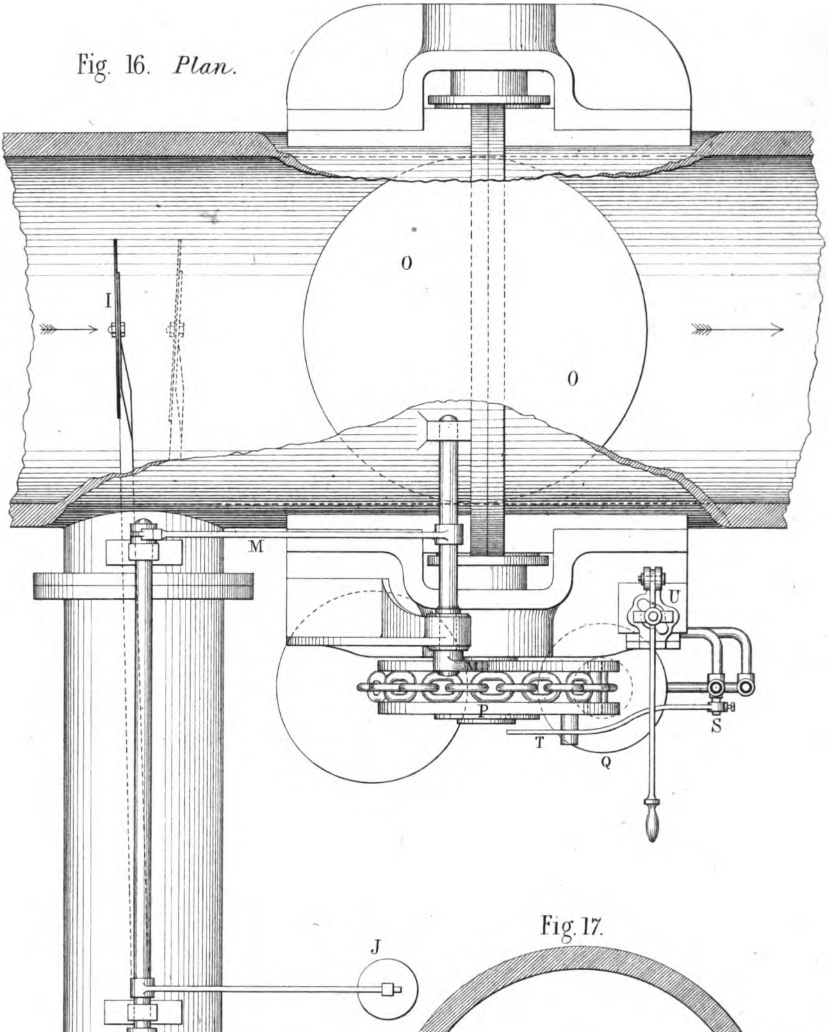
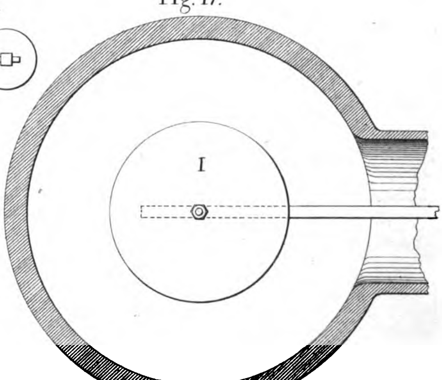


Fig. 17.

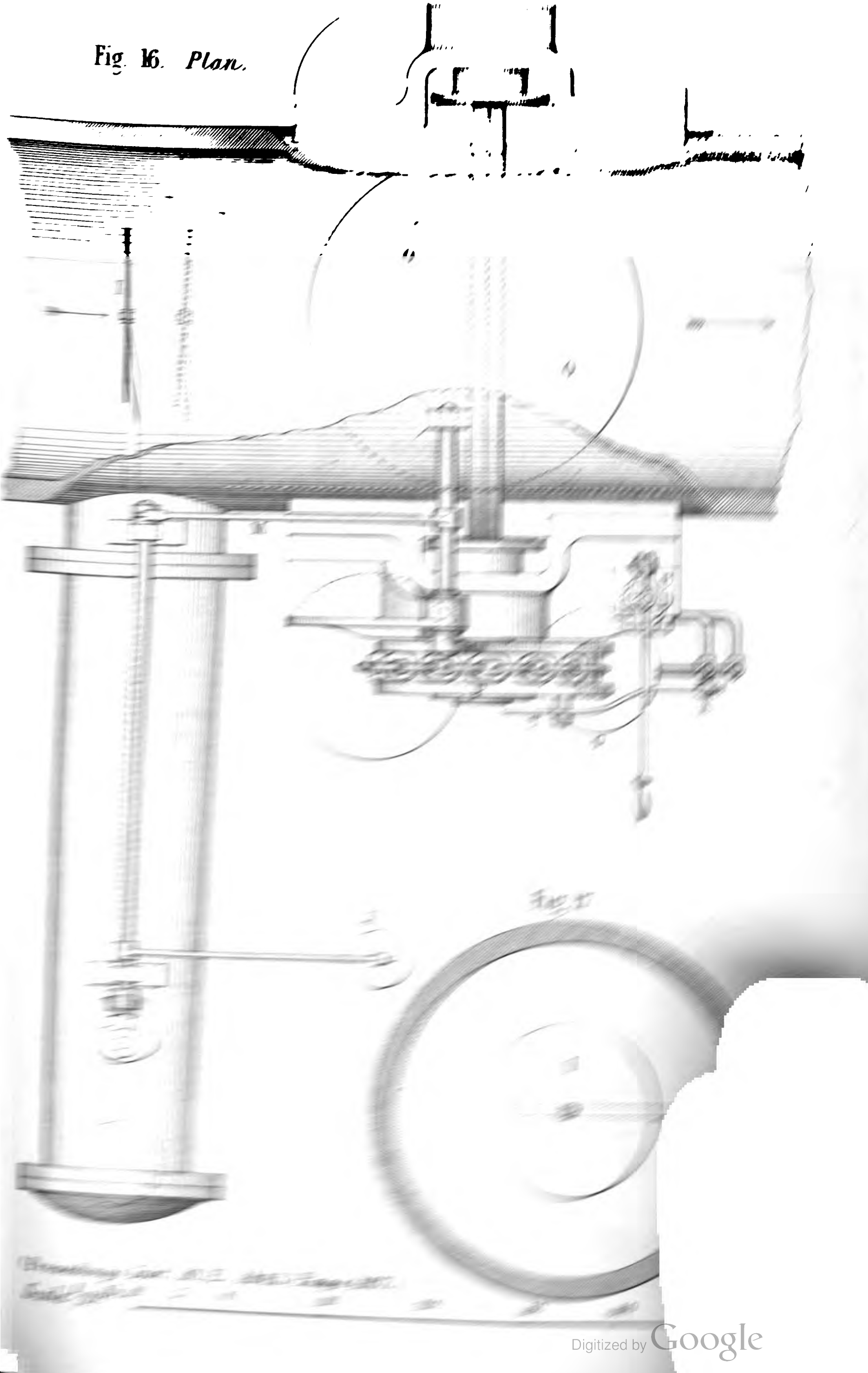


(Proceedings Inst. M. E. 1863. Page 167.)

Scale 1/20th. 10 5 0 10 20 30 40 50 Inches.

Self-acting Throttle Valve in Main

Fig. 16. Plan.



LIVERPOOL WATER WORKS. *Plate 50.*

Self-acting Throttle Valve in Main.

Fig. 16. *Plan.*

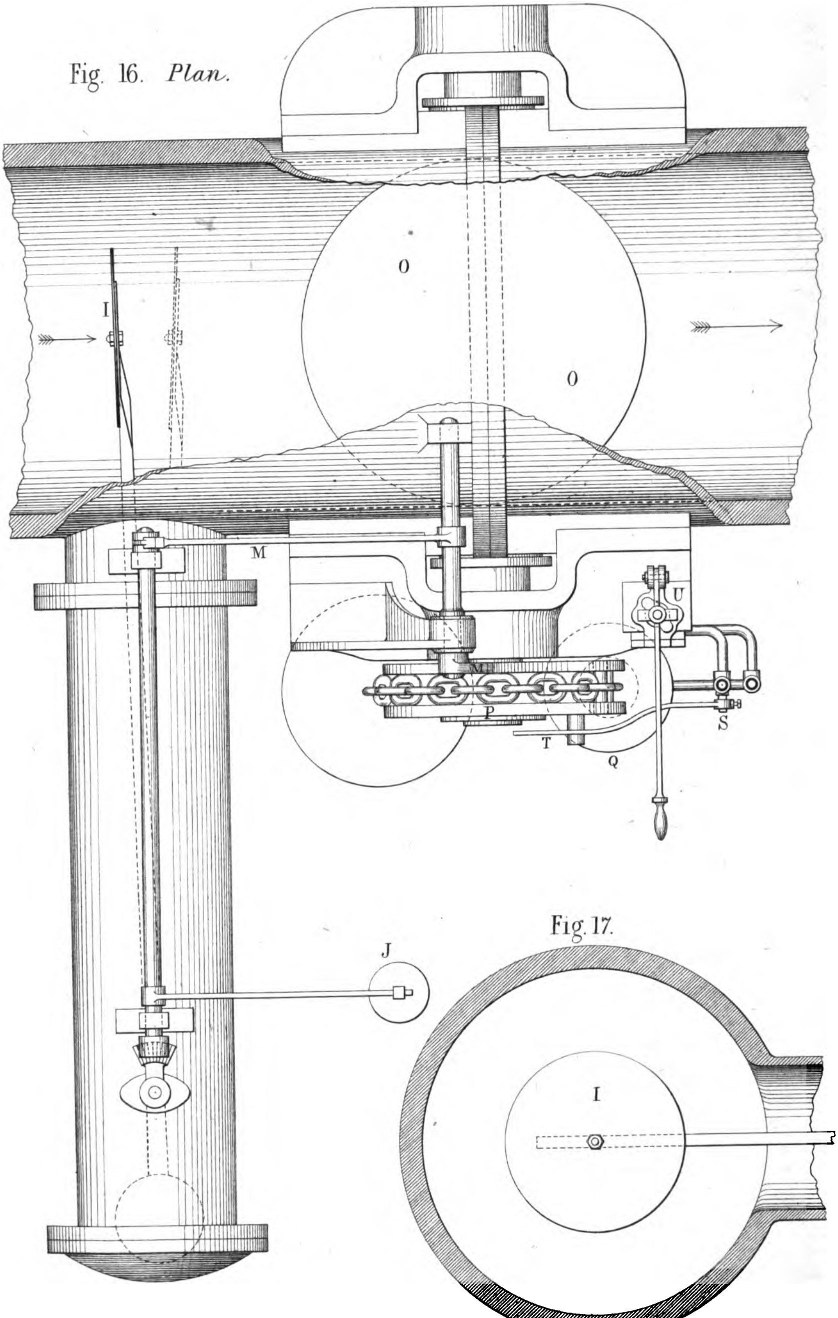


Fig. 17.

(Proceedings Inst. M.E. 1863. Page 167.)

Scale 1/20th. 10 5 0 10 20 30 40 50 *Inches.*

LIVERPOOL WATER WORKS.

Escape Valve on Main.

Fig 18. *Vertical Section.*

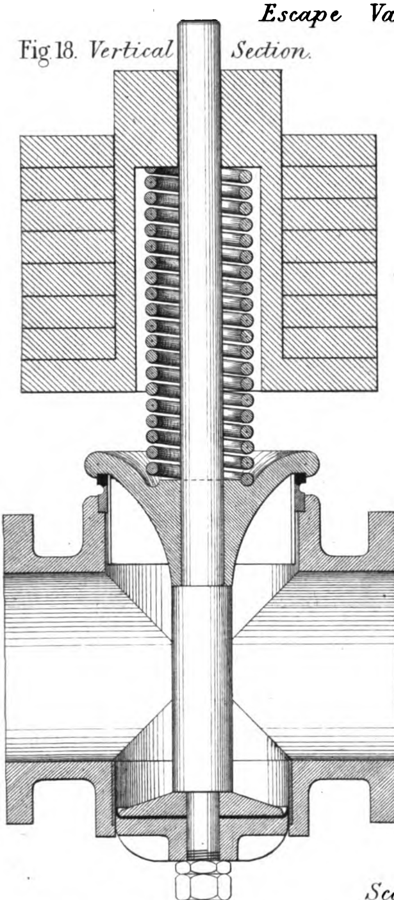
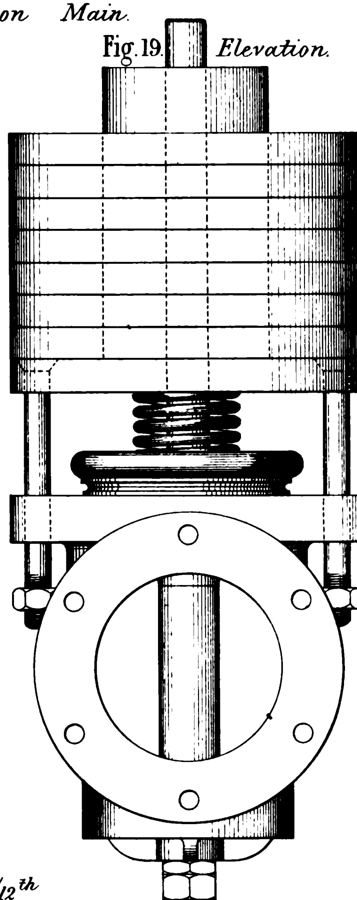


Fig. 19. *Elevation.*



Scale 1/12th

10 5 0 10 20 30 Inches.

Sections of Joints of Main. Scale one quarter full size.

Fig. 20. *Ordinary Lead Joint of 44 inch main.*

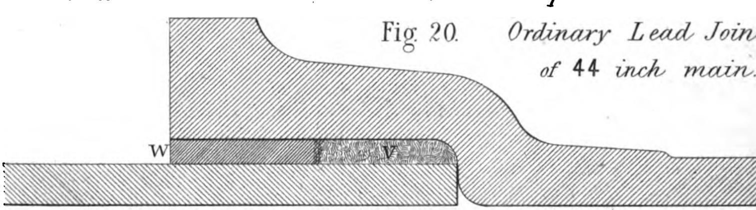
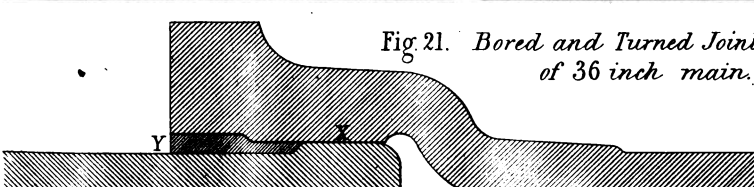


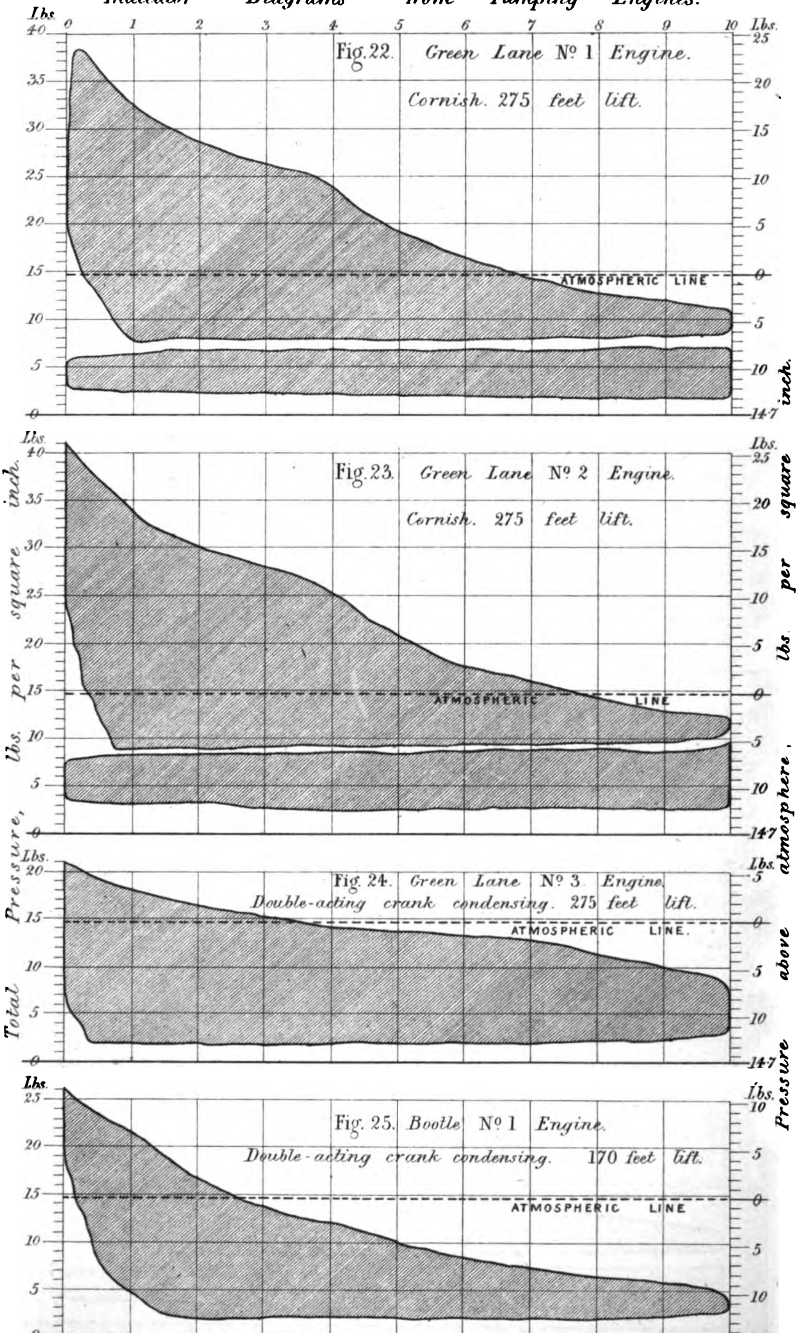
Fig. 21. *Bored and Turned Joint of 36 inch main.*



(Proceedings Inst. M. E. 1863. Page 167.)

LIVERPOOL WATER WORKS. Plate 52.

Indicator Diagrams from Pumping Engines.

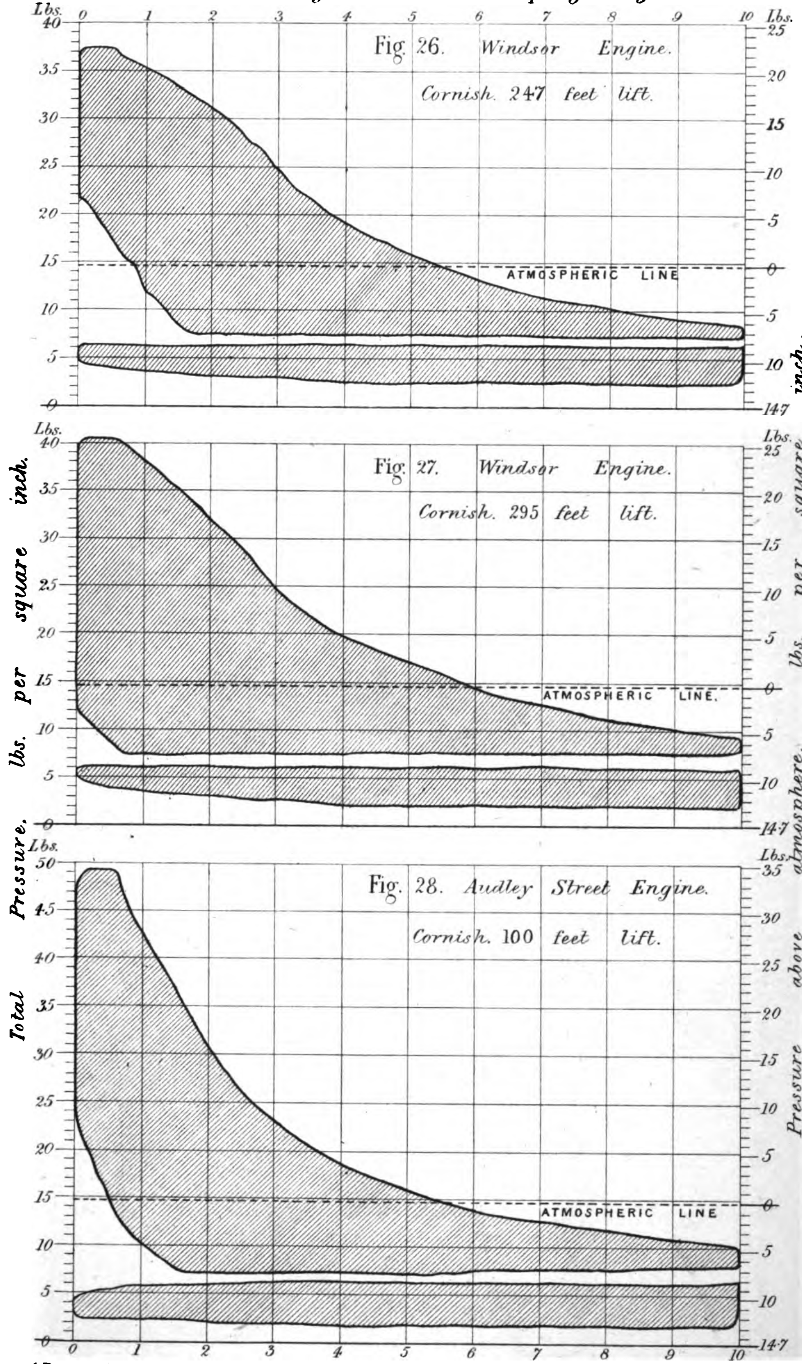


(Proceedings Inst. M.E. 1863. Page 167.)

LIVERPOOL WATER WORKS.

Plate 53.

Indicator Diagrams from Pumping Engines.

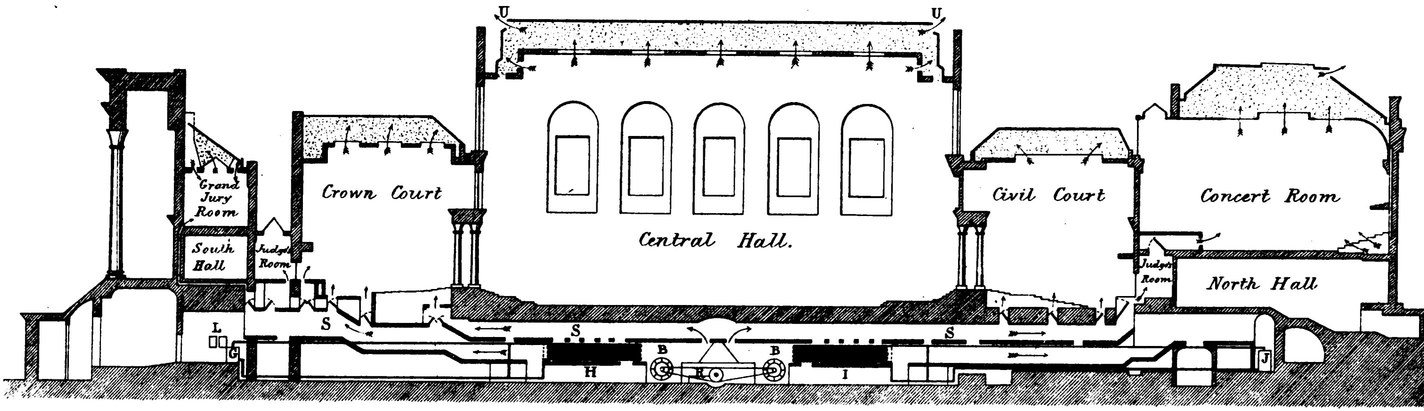


(Proceedings Inst. M.E. 1863. Page 167.)

MECHANICAL VENTILATION AND WARMING.

Plate 54.

Fig. 1. *Longitudinal Section of St. George's Hall, Liverpool.*



Scale 1/800th.

100 50 0 100 200 300 400 Feet.

(Proceedings Inst. M.E. 1863. Page 194.)

MECHANICAL VENTILATION AND WARMING.

Plate 55.

Fig. 2. Basement Plan of St. George's Hall, Liverpool, at level of Upper Air Channels.

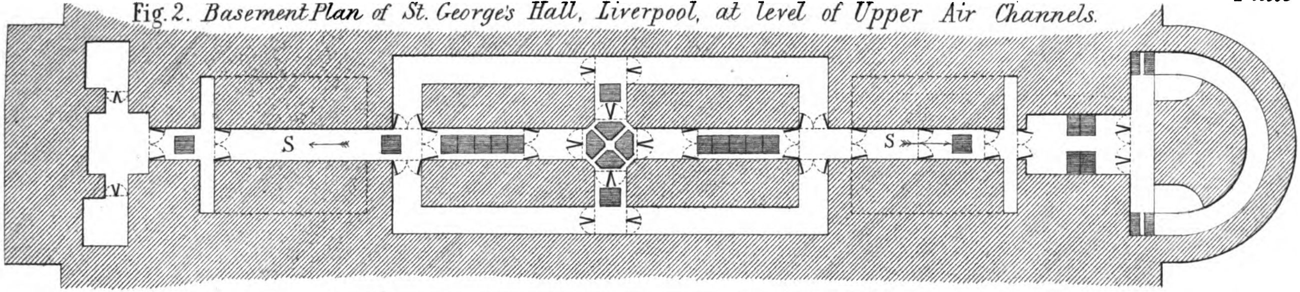
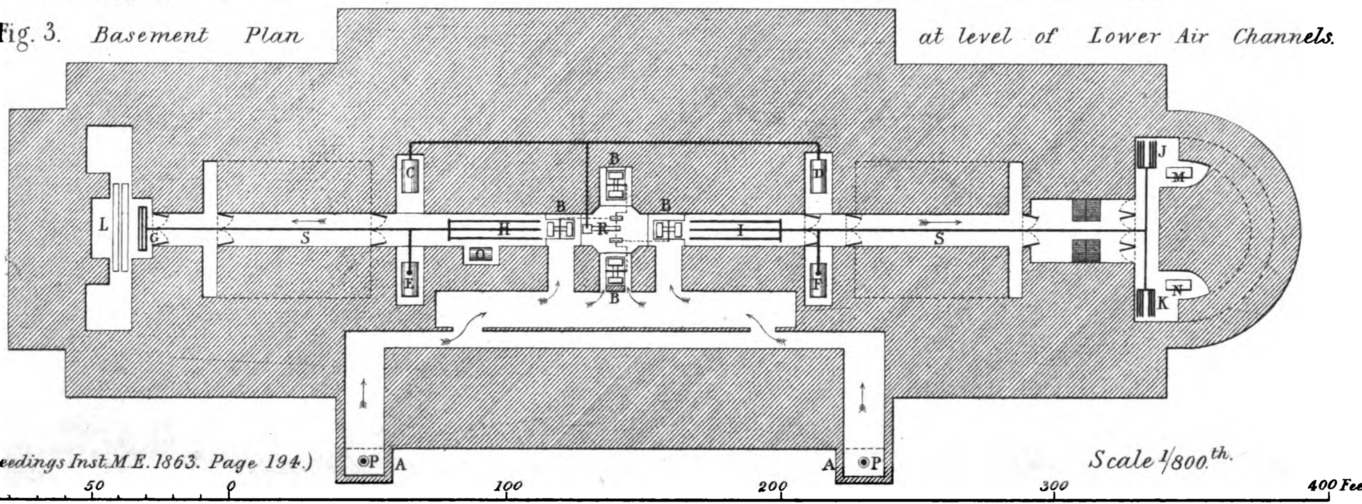


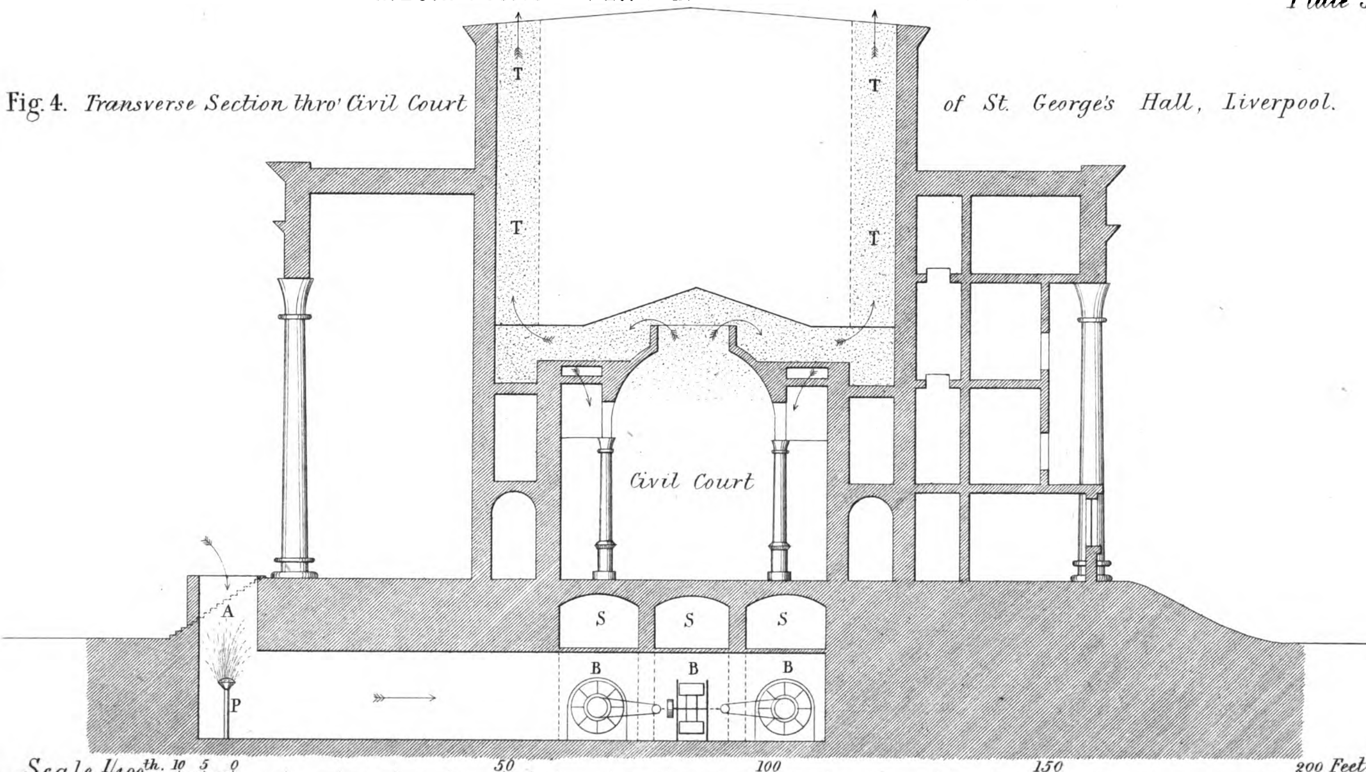
Fig. 3. Basement Plan at level of Lower Air Channels.



(Proceedings Inst. M.E. 1863. Page 194.)

Scale 1/800th.

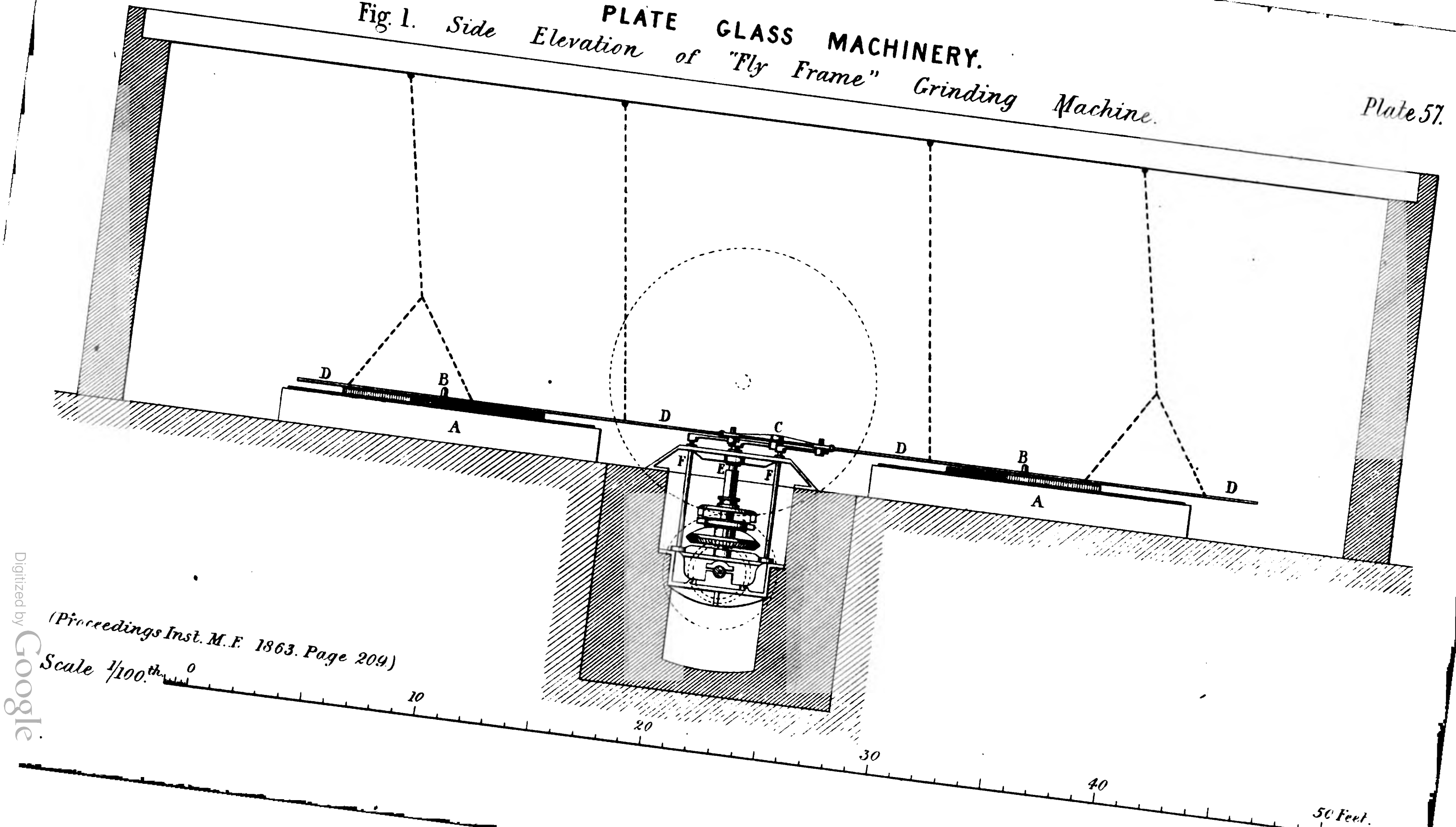
Fig. 4. *Transverse Section thro' Civil Court of St. George's Hall, Liverpool.*



(Proceedings Inst. M.E. 1863. Page 194.)

PLATE GLASS MACHINERY.

Fig. 1. *Side Elevation of "Fly Frame" Grinding Machine.*



(Proceedings Inst. M.E. 1863. Page 209.)

PLATE GLASS MACHINERY.

Fig. 2. *Plan of "Fly Frame" Grinding Machine.*

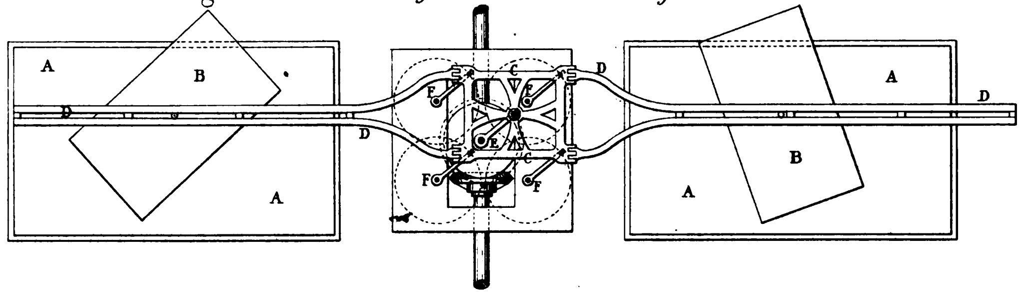
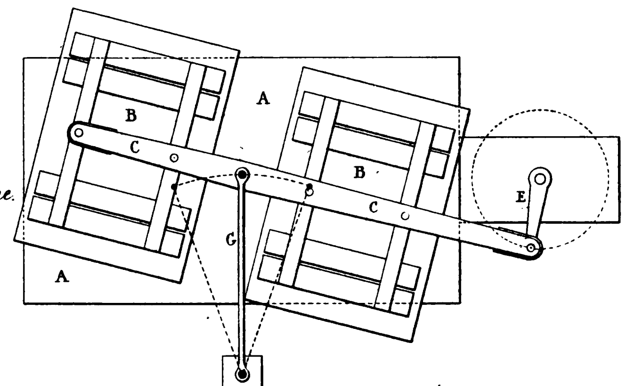


Fig. 3. *Plan of Smoothing Machine.*



(Proceedings Inst. M.E. 1863. Page 209.)

Scale 1/100th. 0 10 20 30 40 50 Feet.

PLATE GLASS MACHINERY.

Plate 59.

Polishing Machine. Fig. 4. *Side Elevation.*

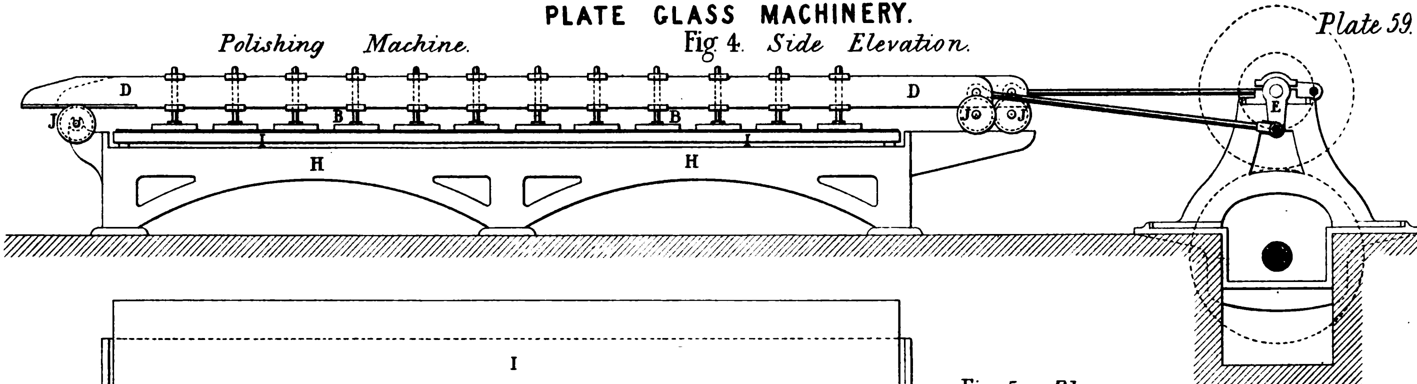
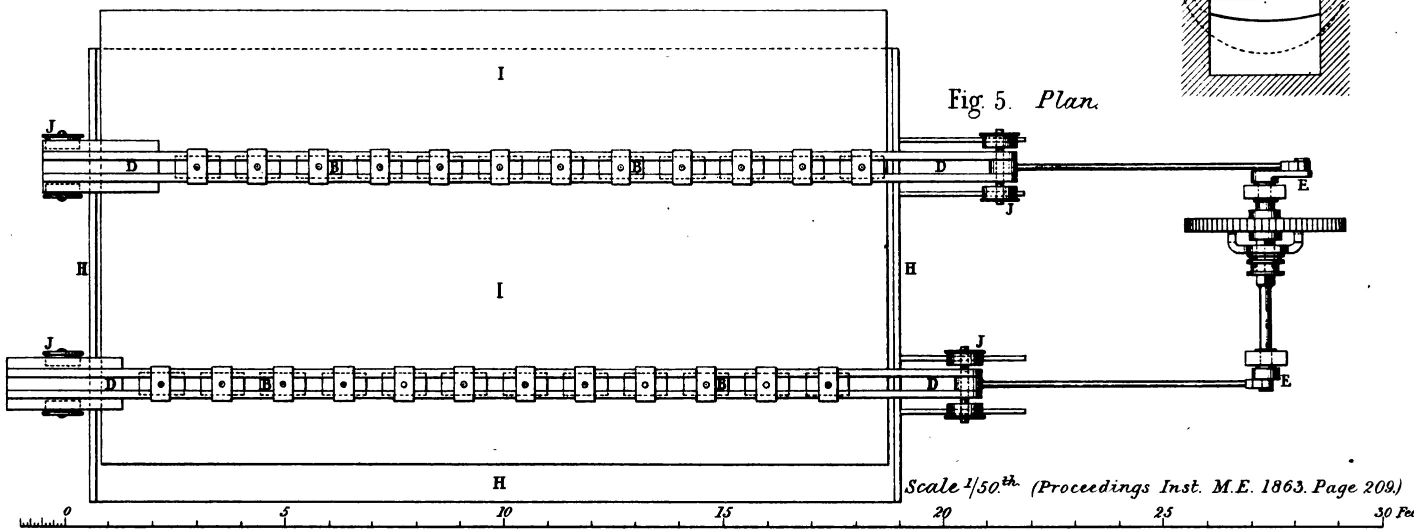


Fig. 5. *Plan.*



Scale 1/50th. (Proceedings Inst. M.E. 1863. Page 209.)

Improved Grinding and Smoothing Machine.

Fig. 6. *Elevation.*

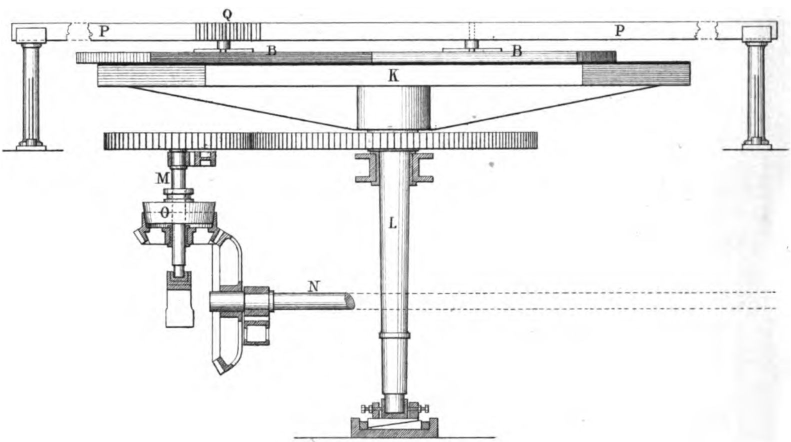
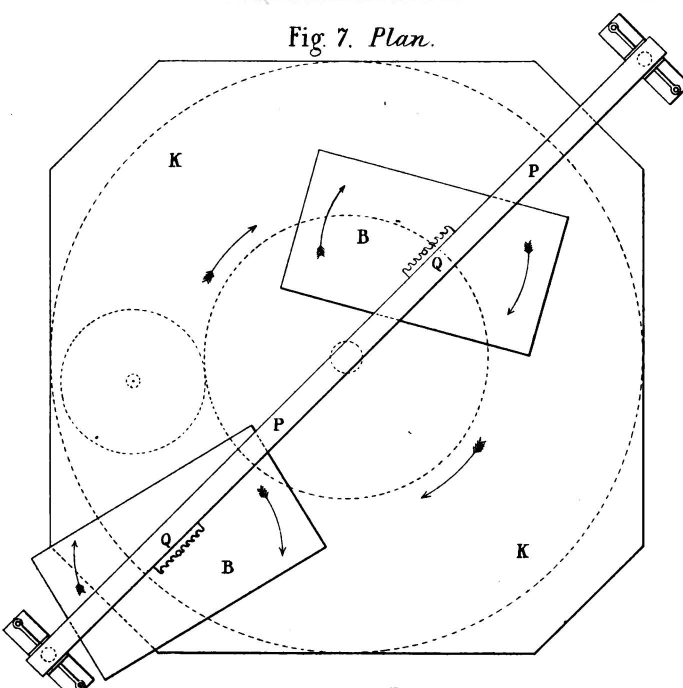


Fig. 7. *Plan.*



Scale 1/80.th.

0 5 10 15 20 25 *Feet.*

GROSMONT IRON WORKS.

Plate 61.

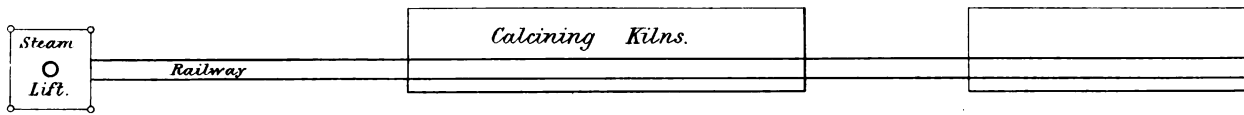
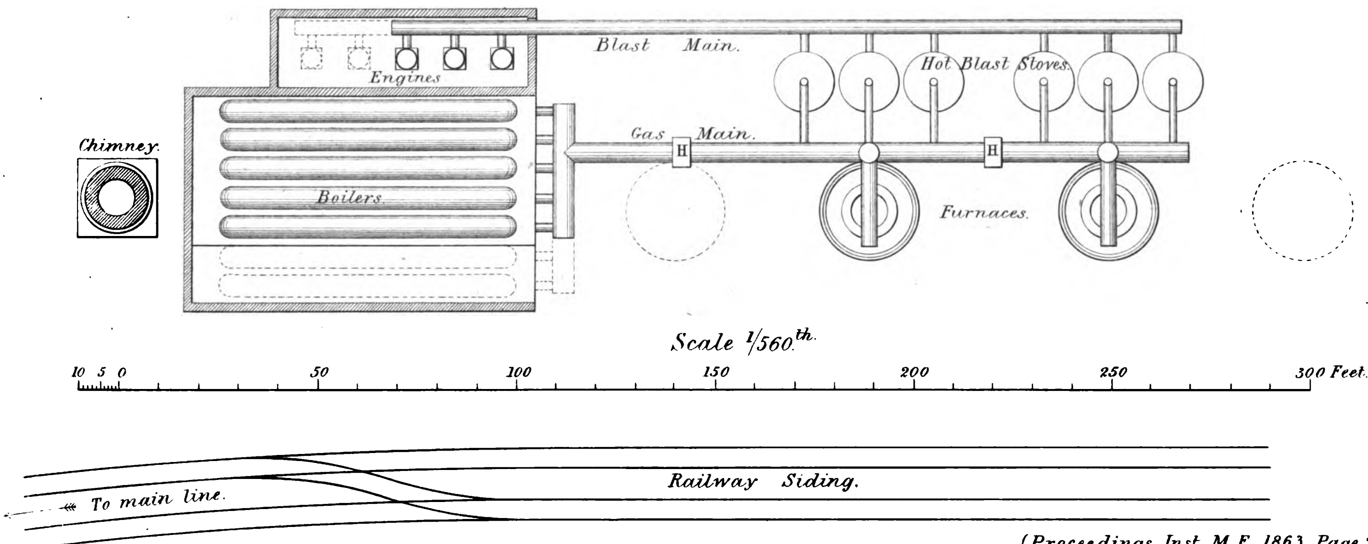
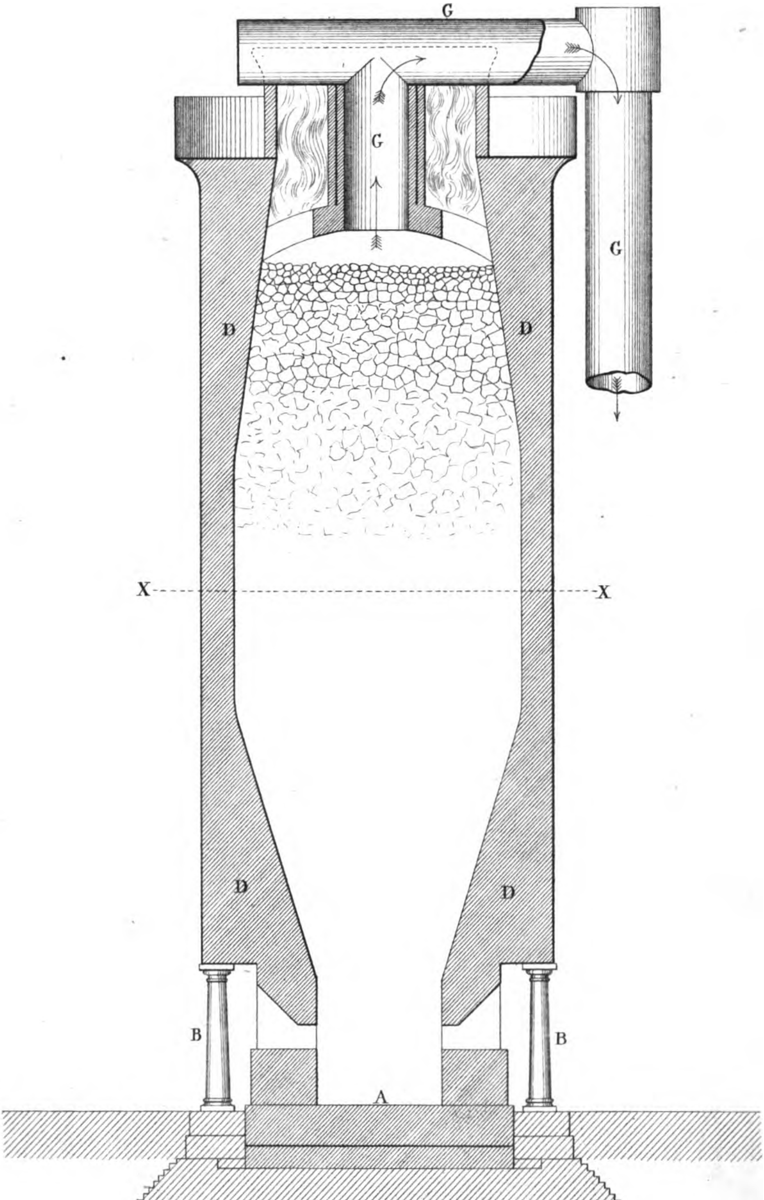


Fig. 1. *General Plan of Works.*



(Proceedings Inst. M.E. 1863. Page 225)

Fig. 2. *Vertical Section of Blast Furnace.*

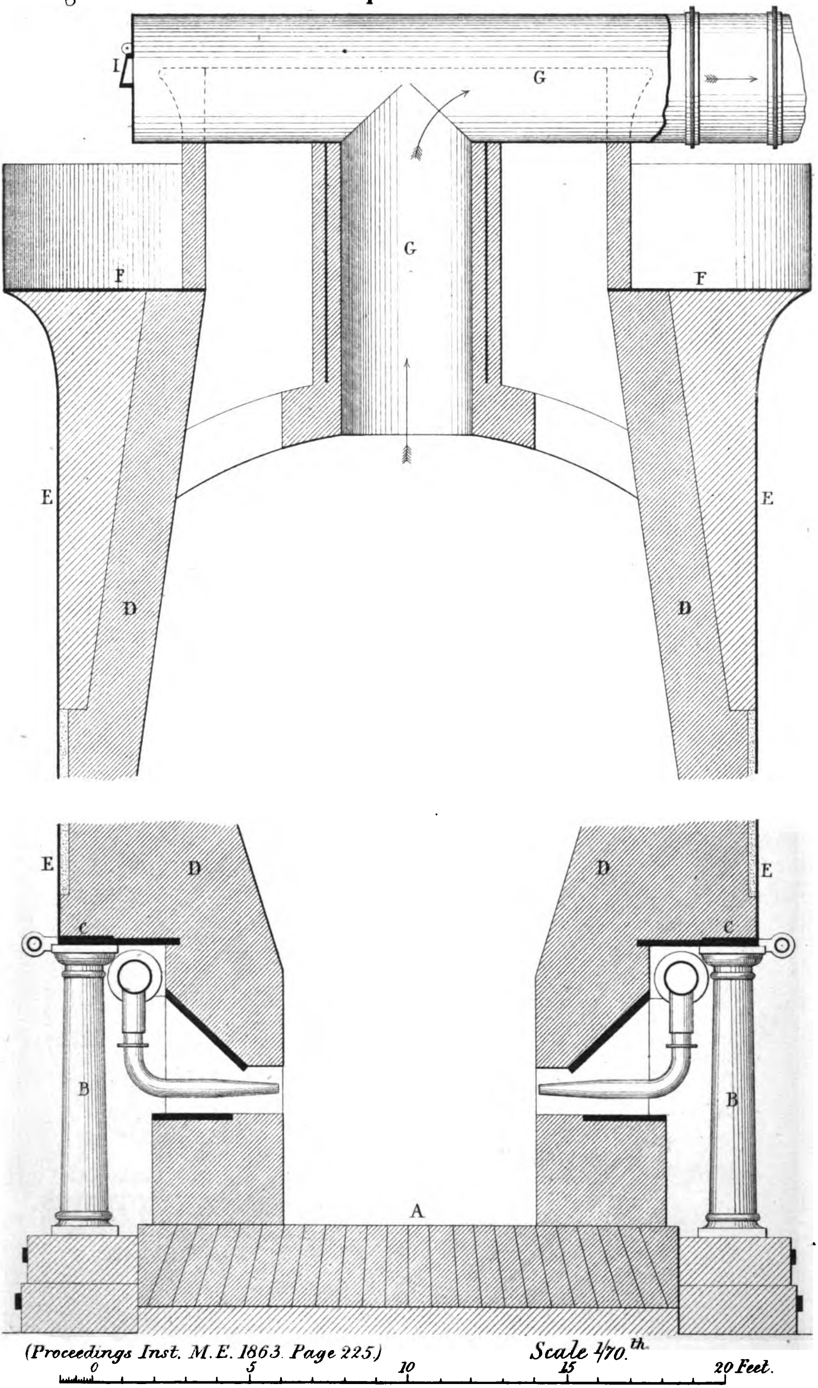


(Proceedings Inst. M.E. 1863. Page 225.)

Scale 1/140th.

0 10 20 30 40 Feet.

Fig. 3. *Vertical Section of top and bottom of Blast Furnace.*



(Proceedings Inst. M.E. 1863. Page 225.) *Scale 1/70th.*

Transverse Sections of Blast Furnace.

Fig. 4. *At Tuyeres.*

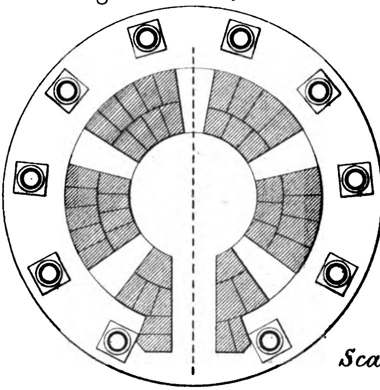
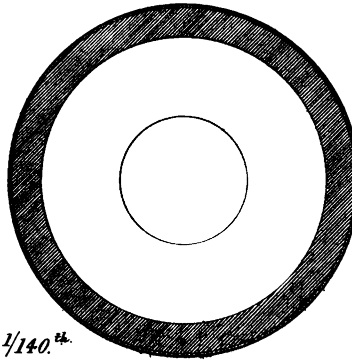


Fig. 8. *At XX (Fig. 2.)*



Scale 1/140.th

10 5 0 10 20 Feet.

Fig. 5. *At Tapping Hole.*

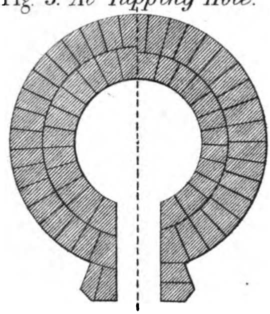


Fig. 9. *Longitudinal Section of Tuyere Pipe.*

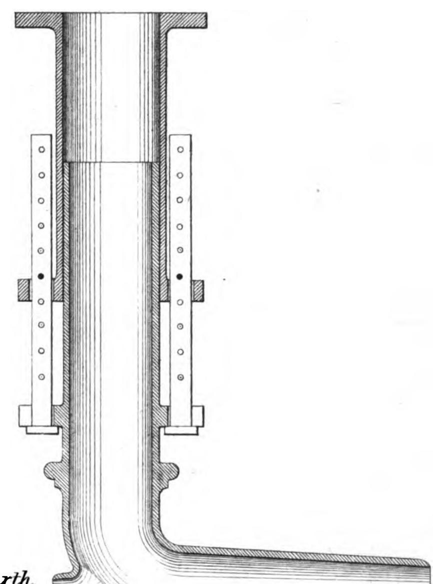


Fig. 6. *At Hearth.*

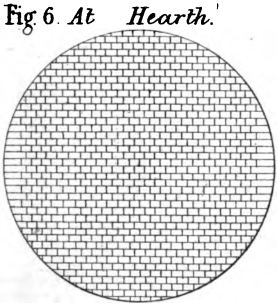


Fig. 7. *Vertical Section of Hearth.*

Scale 1/140.th

Scale 1/12.th

0 10 20 Inches.

(Proceedings Inst. M.E. 1863. Page 225.)

GROSMONT IRON WORKS.

Hot - Blast Stove.

Plate 65.

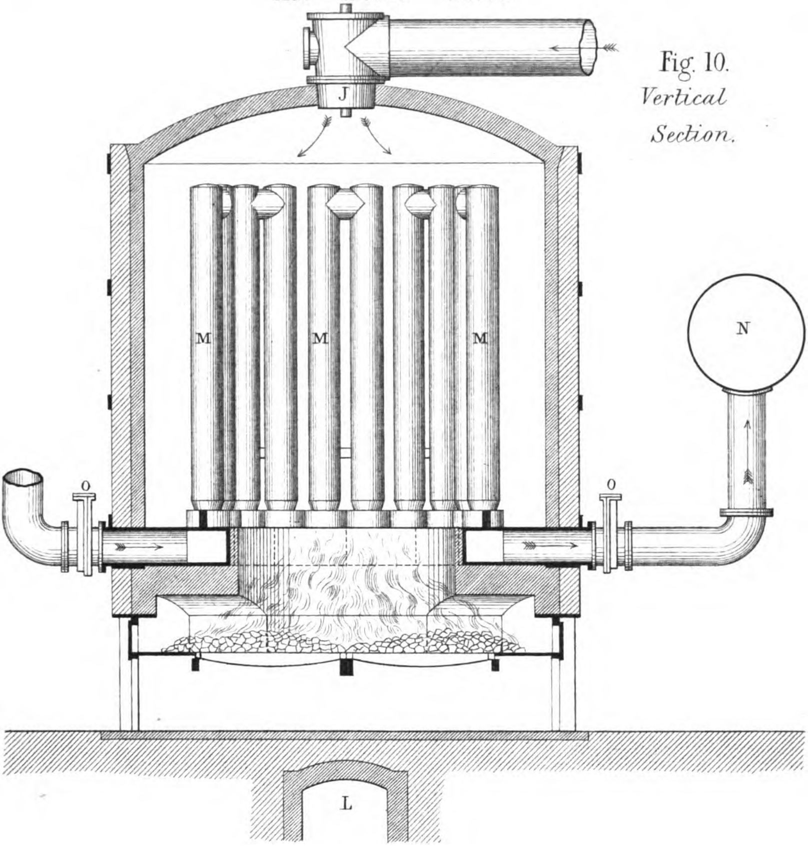
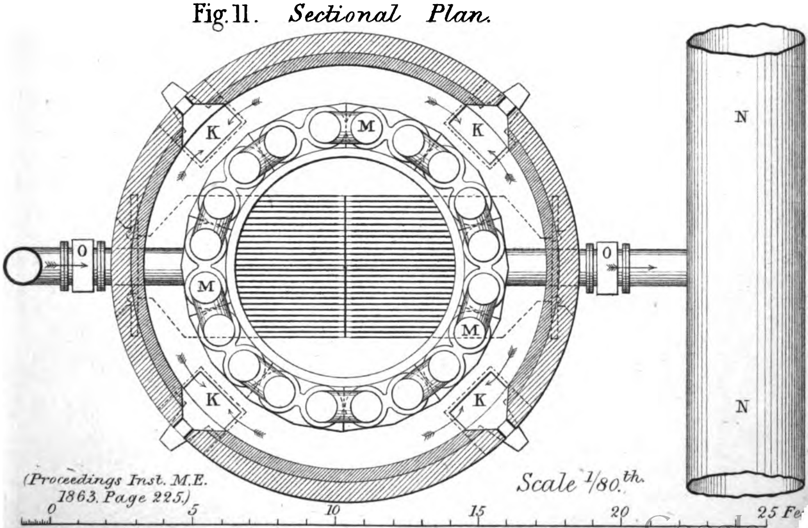


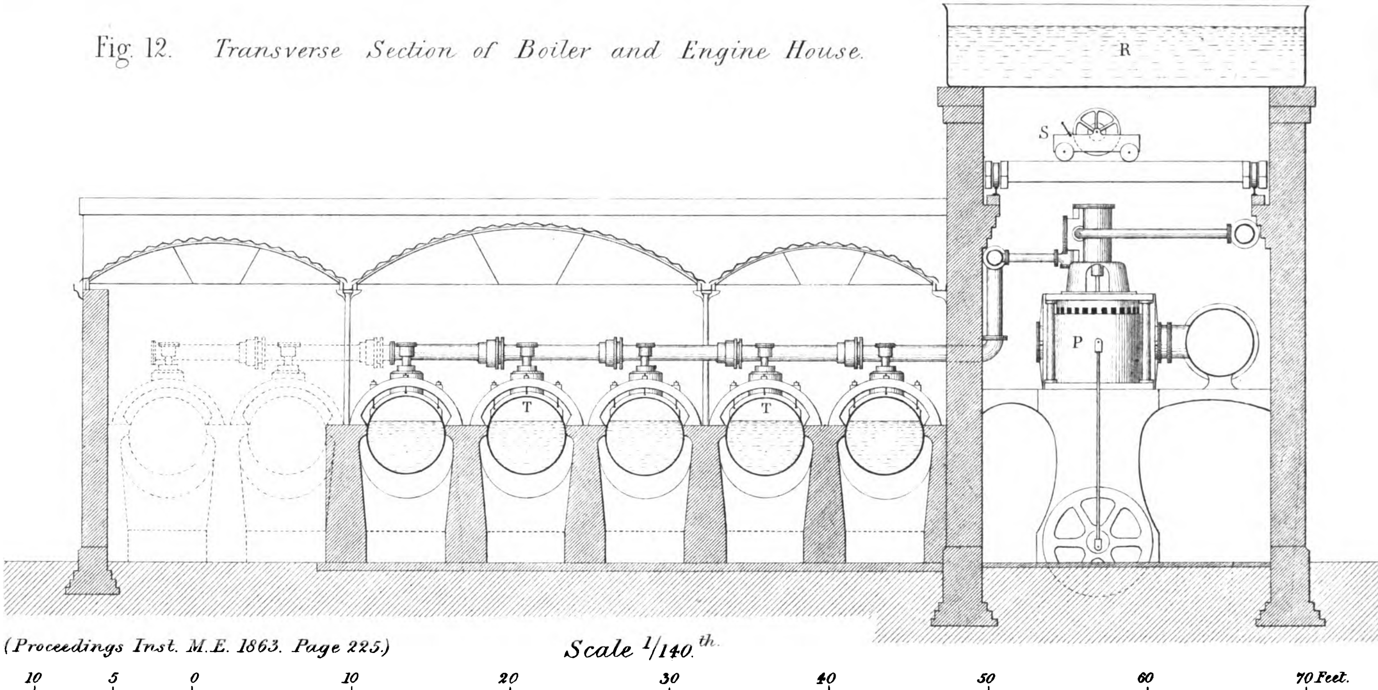
Fig. 10. *Vertical Section.*

Fig. 11. *Sectional Plan.*



(*Proceedings Inst. M.E. 1863. Page 225.*)

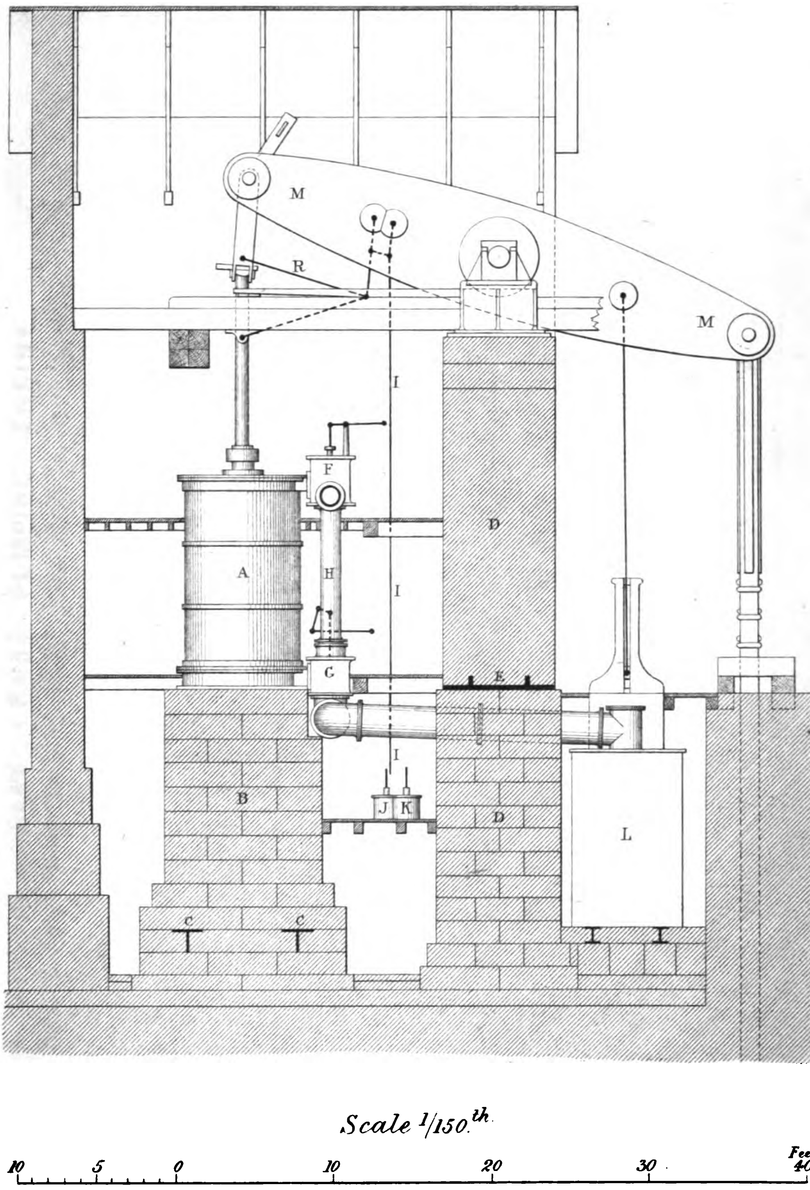
Fig. 12. Transverse Section of Boiler and Engine House.



(Proceedings Inst. M.E. 1863. Page 225.)

Scale 1/140.th

Fig. 1. *Side Elevation of Engine.*



(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE.

Fig. 2. *Longitudinal Section and Elevation of Wrought Iron Beam.*

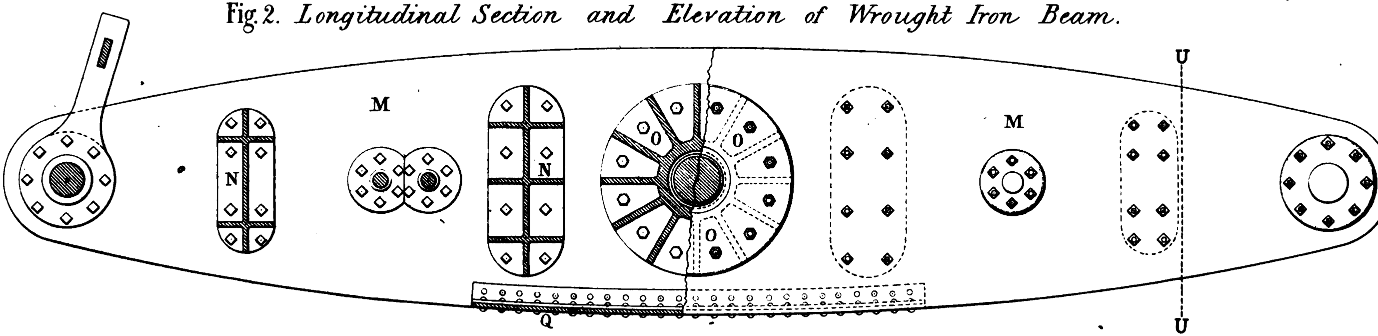
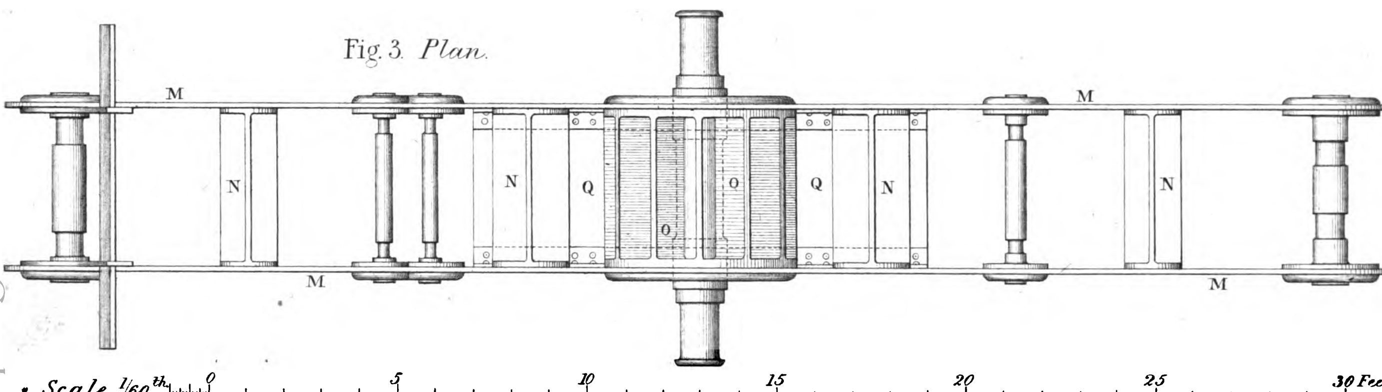


Fig. 3. *Plan.*



• *Scale 1/60.th*

(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE. *Plate 69.*

Transverse Sections of Wrought Iron Beam.

Fig. 4. *At Centre.*

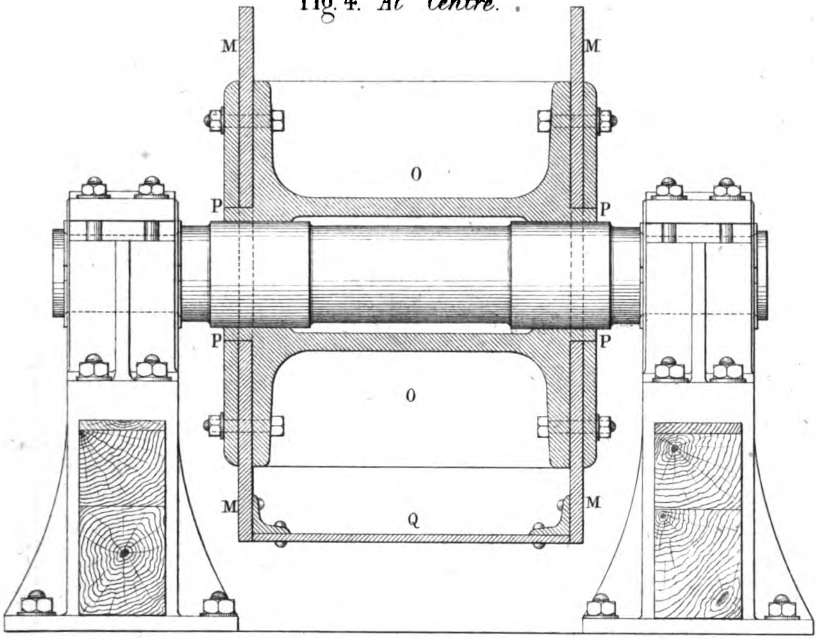


Fig. 5. *At* UU *(Fig. 2)*

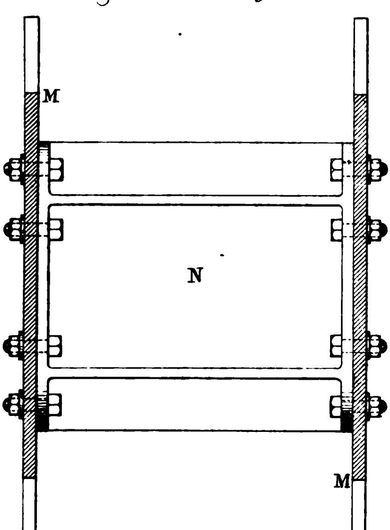
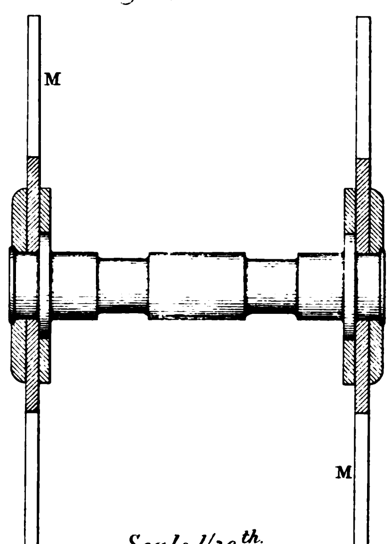


Fig. 6. *At End.*



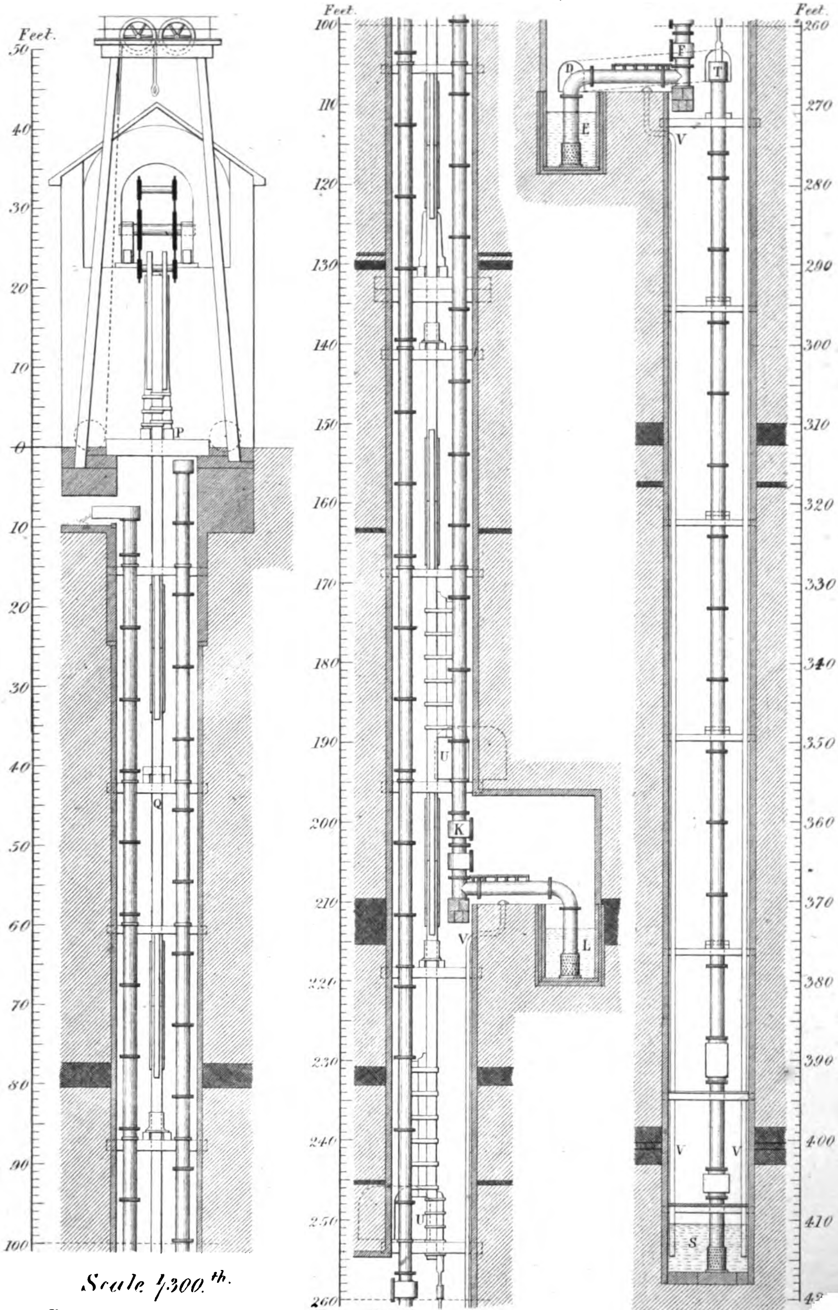
(Proceedings Inst. M.E. 1863 Page 248)

Scale 1/30th.

10 5 0 10 20 30 40 50 60 70 80 90 100 *Inches.*

CLAY CROSS PUMPING ENGINE. *Plate 70.*

Fig. 7. Vertical Section of Pit.

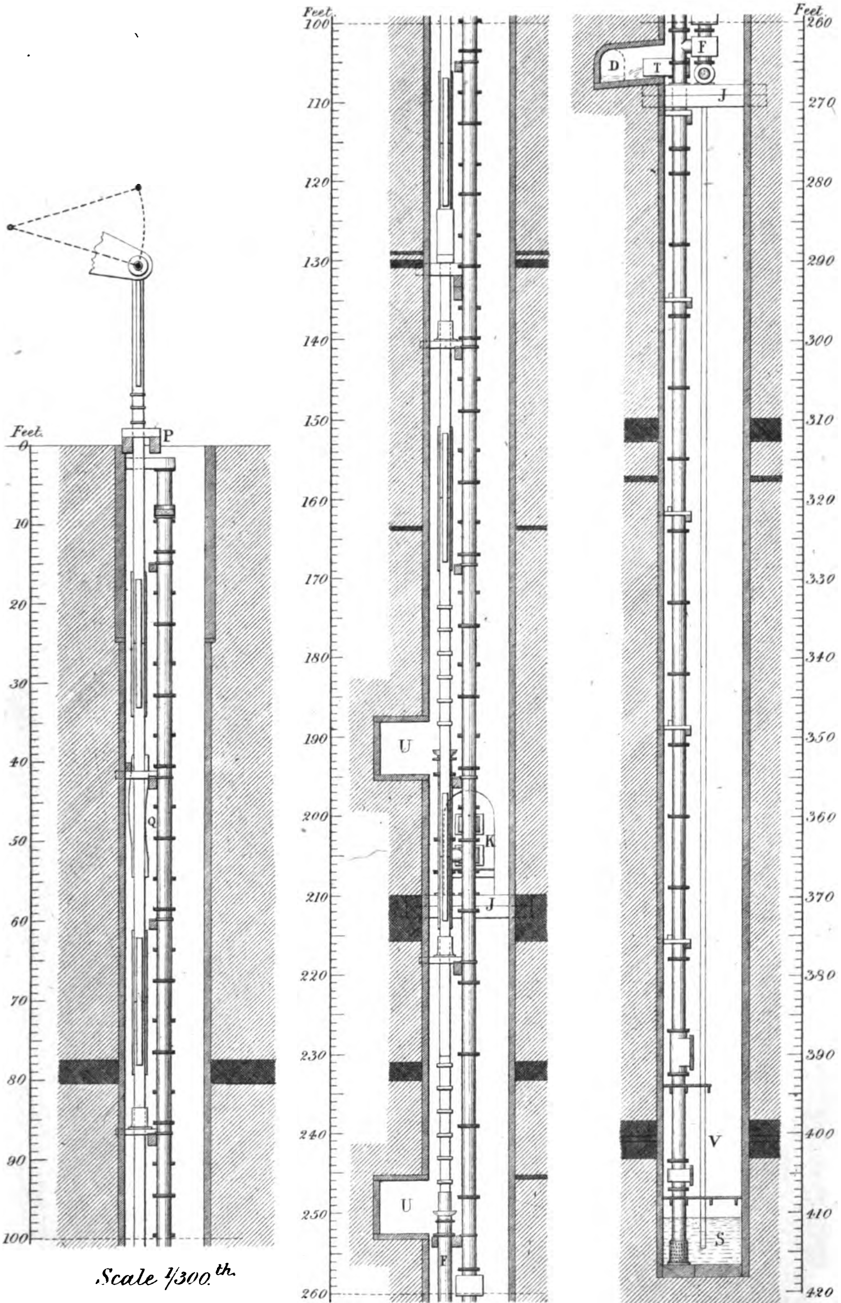


Scale 1/300th.

(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE.

Fig. 8. *Vertical Section of Pit, taken at right angles to Fig. 7.*



Scale 1/300th

(Proceedings Inst. M.E. 1863. Page 248.)

Fig. 9. *Sectional Plan of Pit at Upper Plunger Pump.*

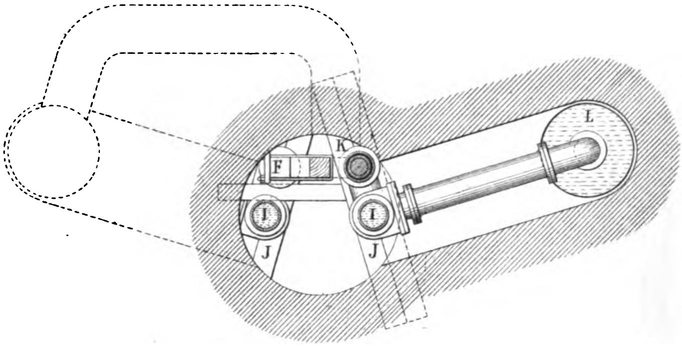


Fig. 10. *Sectional Plan of Pit at Lower Plunger Pump.*

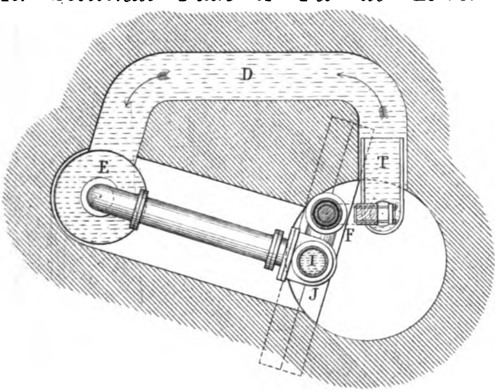
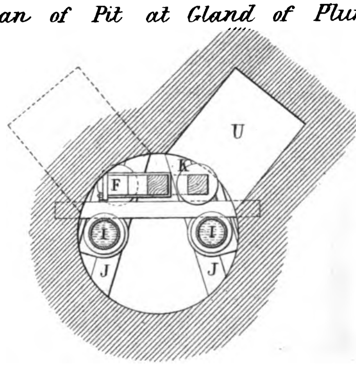
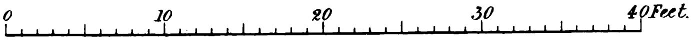


Fig. 11. *Sectional Plan of Pit at Gland of Plunger Pump.*

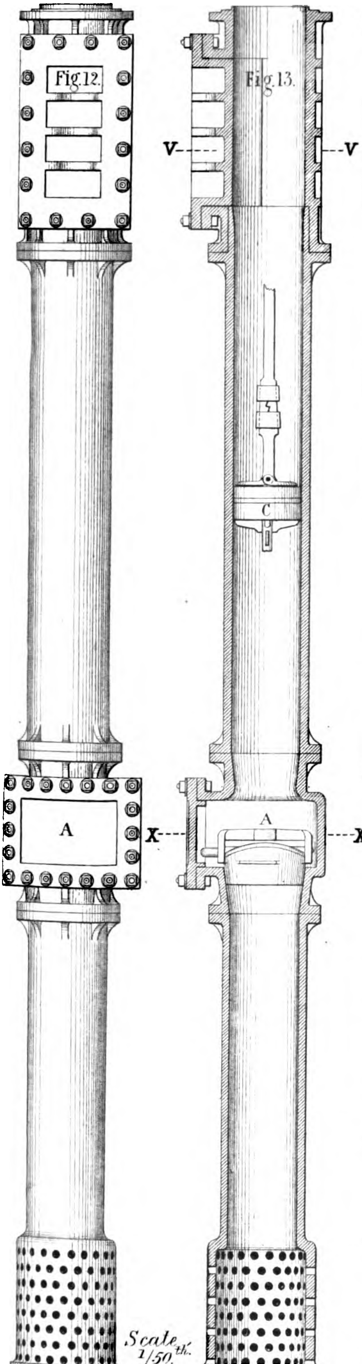


Scale 1/150th.



(Proceedings Inst. M.E. 1863. Page 248.)

Bucket Pump.



Scale 1/50th.

Fig. 16. *Section of Bucket.*

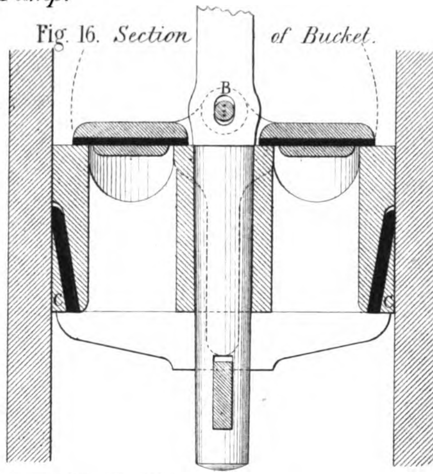
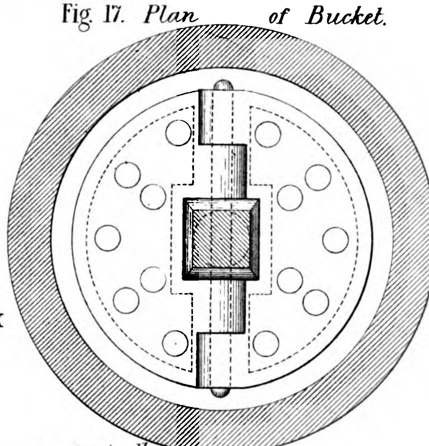


Fig. 17. *Plan of Bucket.*



Scale 1/10th.

Inches. 0 5 10 15 20

Fig. 14.
Sectional Plan at **VV.**

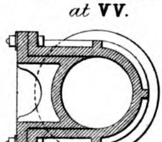
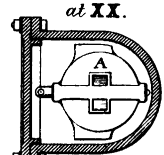


Fig. 15.
Sectional Plan at **XX.**



Scale 1/50th.

(Proceedings Inst. M.E. 1863. Page 248.)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 *Feet.*

CLAY CROSS PUMPING ENGINE. *Plate 74.*

Detail of Pump Clacks, enlarged.

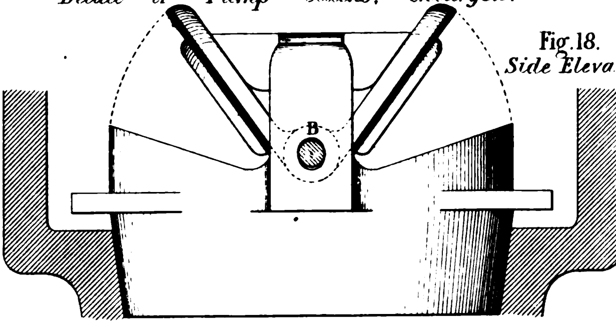


Fig. 18. *Side Elevation.*

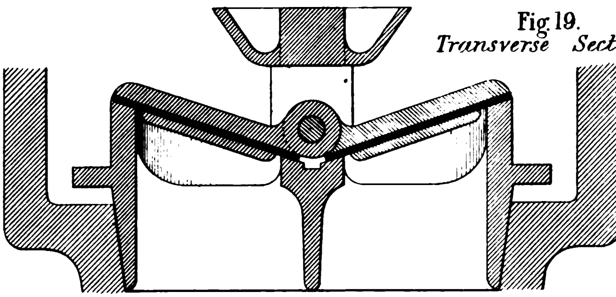


Fig. 19. *Transverse Section.*

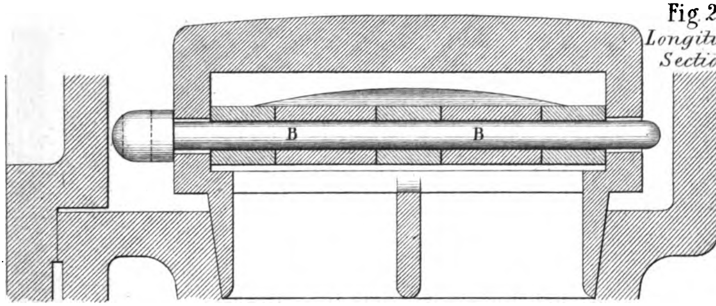


Fig. 20. *Longitudinal Section.*

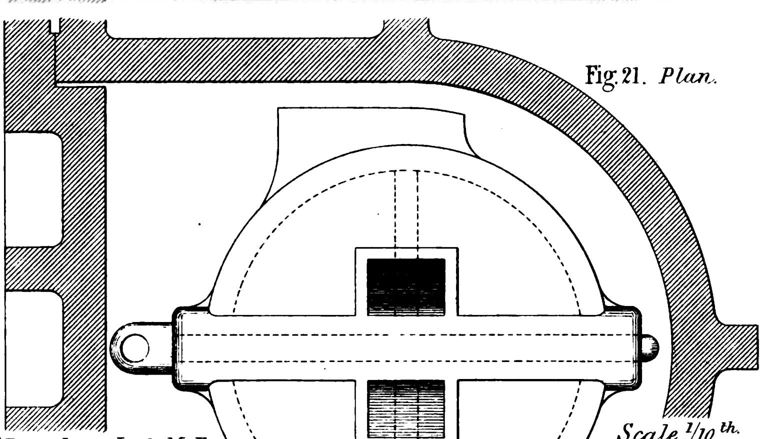


Fig. 21. *Plan.*

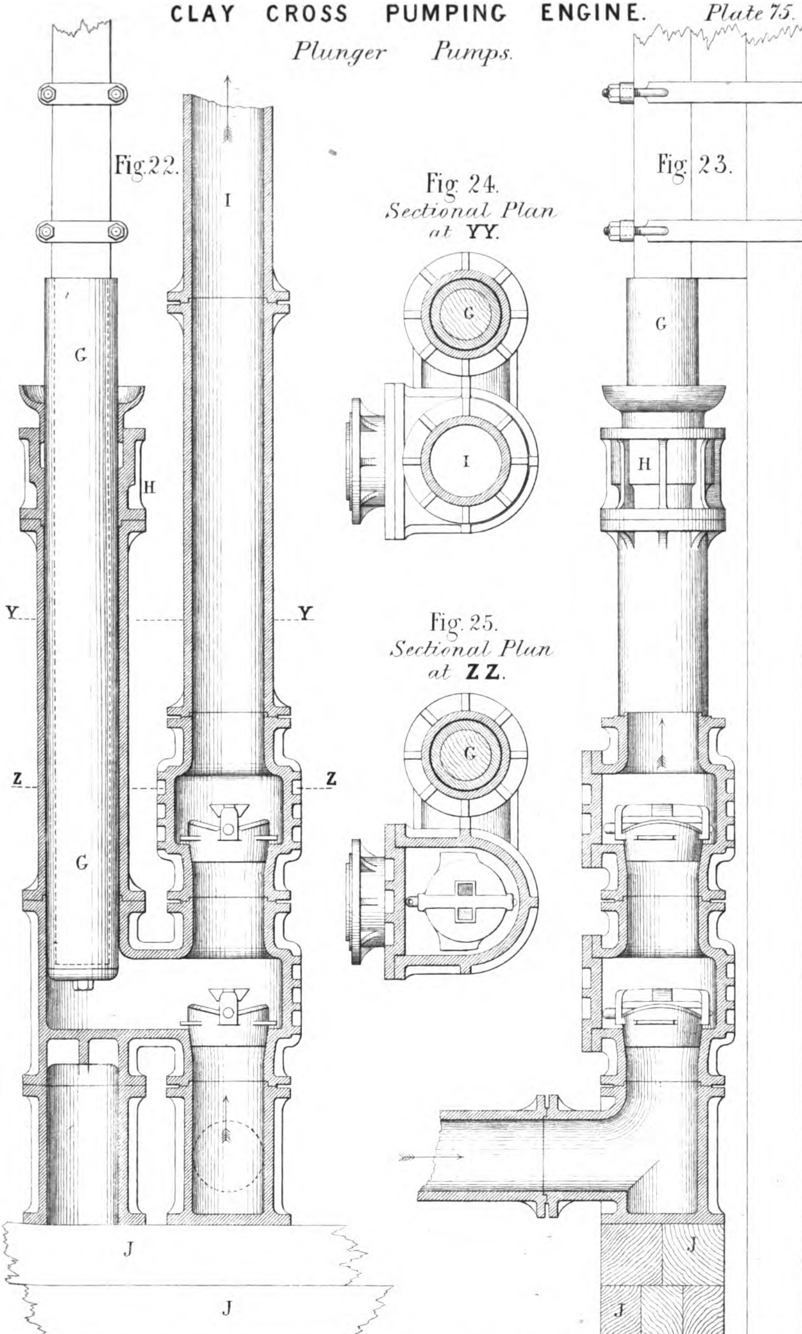
Scale 1/10th.

10 5 0 10 20 *Inches.*

(Proceedings Inst. M.E. 1863. Page 248.

CLAY CROSS PUMPING ENGINE. *Plate 75.*

Plunger Pumps.



(Proceedings Inst. M.E. 1863. Page 248.) *Scale 1/50.th*

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

CLAY CROSS PUMPING ENGINE. *Plate 76.*

Joints of 19 inch Rising Mains of Pumps.

Fig. 26. *At bottom of Main.*

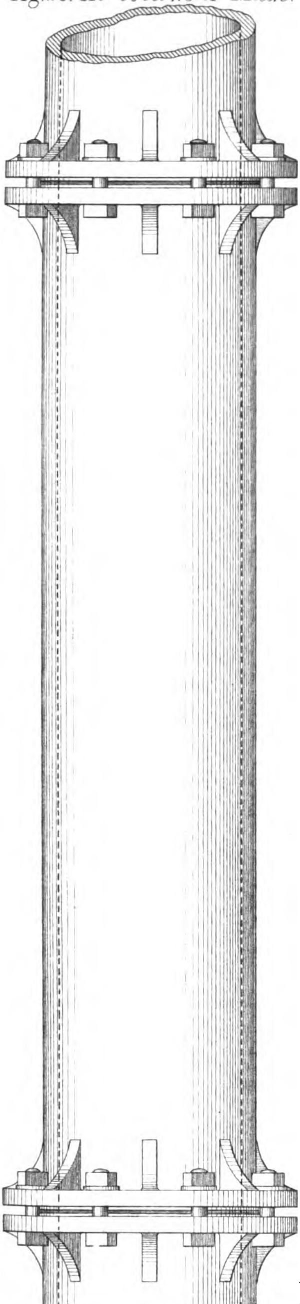


Fig. 27. *At top of Main.*

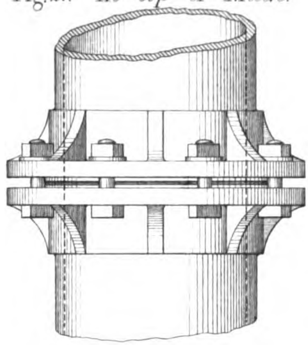


Fig. 29. *Enlarged Section of Joint. Scale 1/4.th*

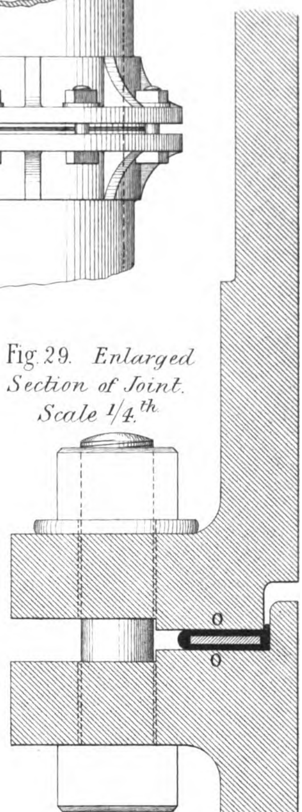
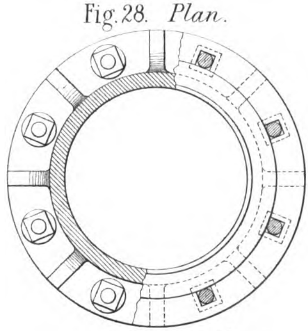


Fig. 28. *Plan.*

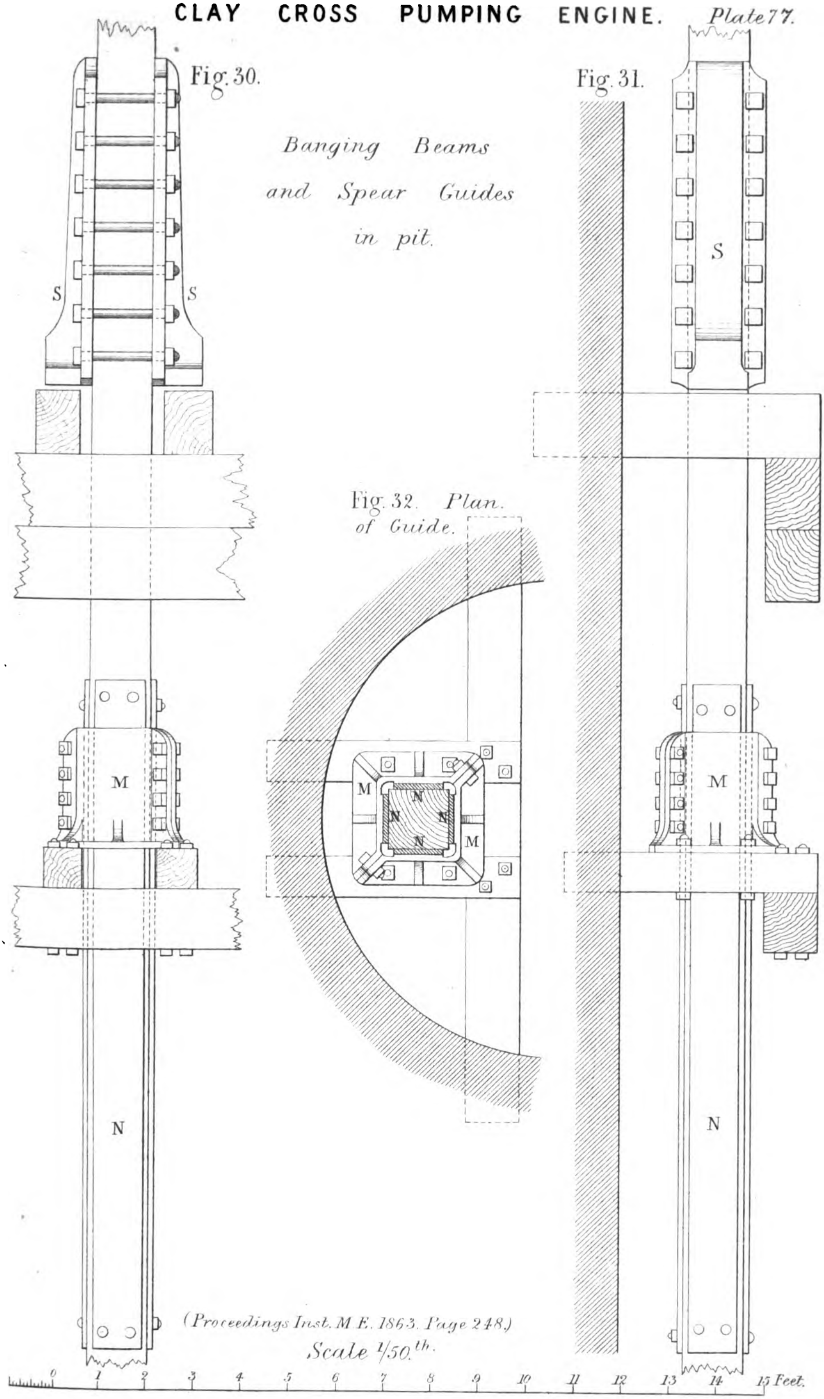


Scale 1/20.th

10 5 0 10 20 30 *Inches.*

(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE. *Plate 77.*



(Proceedings Inst. M. E. 1863. Page 248.)

Scale 1/50th.

CLAY CROSS PUMPING ENGINE.

Plate 77.

Banging Beams and Spear Guides in pit.

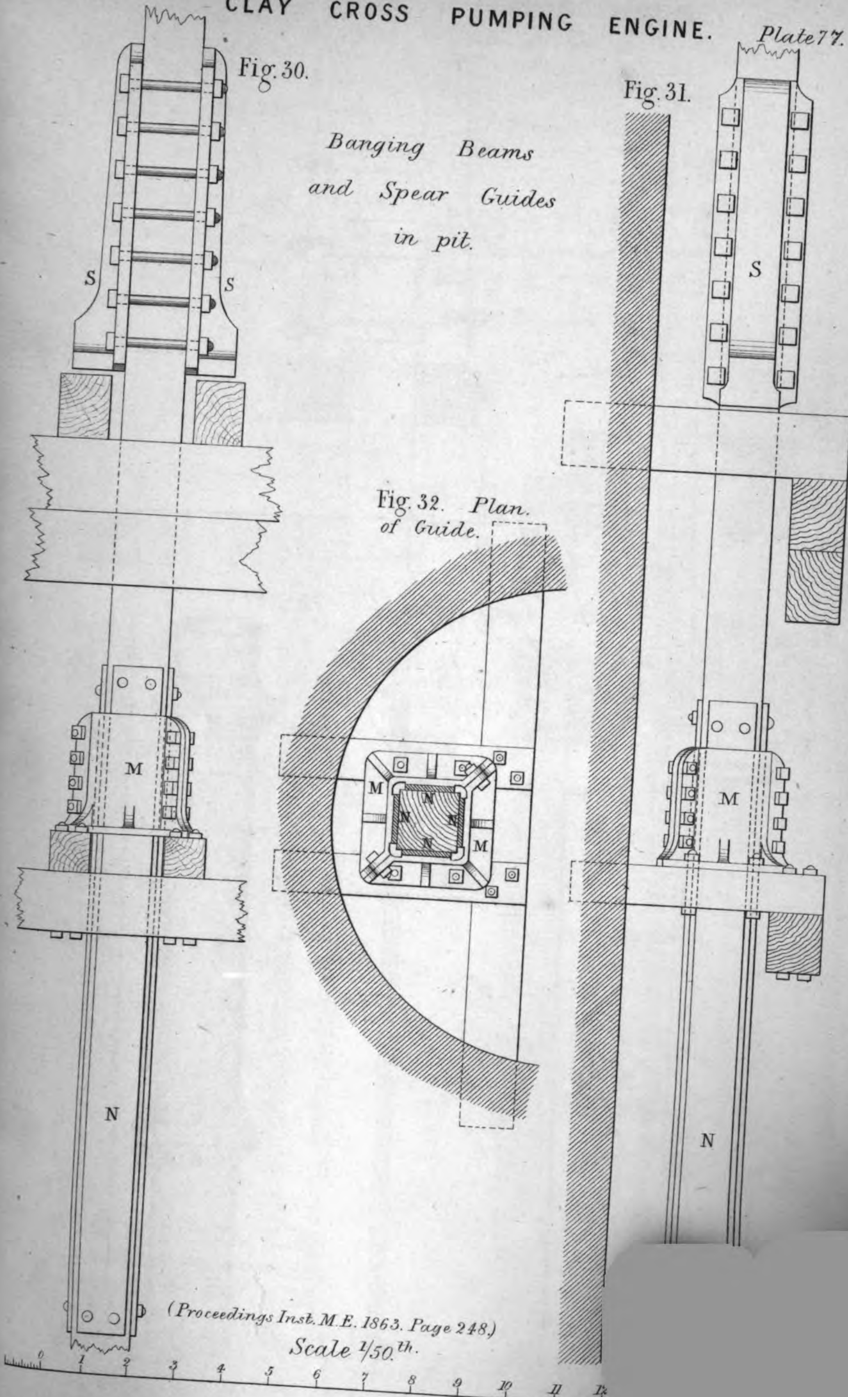


Fig. 30.

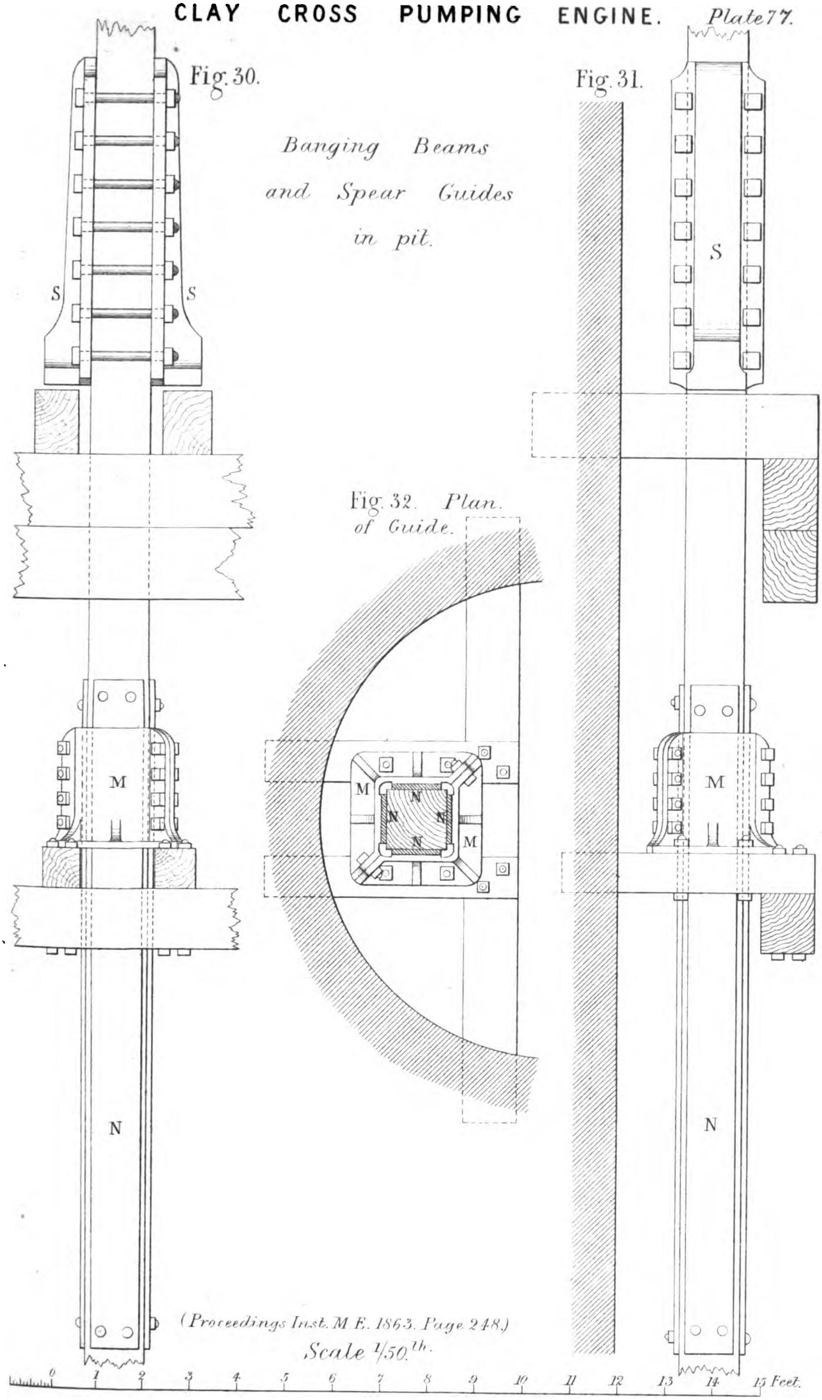
Fig. 31.

Fig. 32. Plan. of Guide.

(Proceedings Inst. M.E. 1863. Page 248.)

Scale 1/50th.

CLAY CROSS PUMPING ENGINE. *Plate 77.*



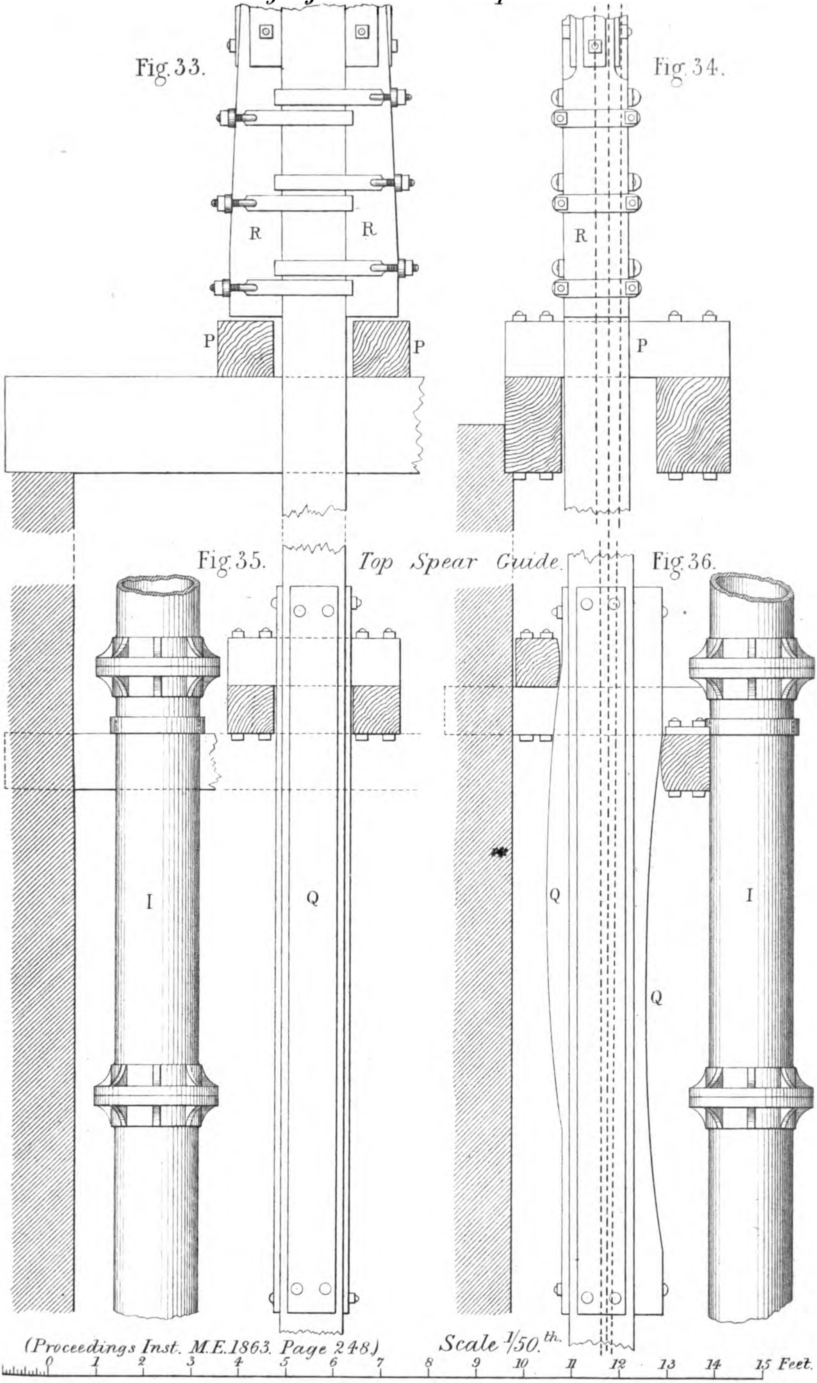
(Proceedings Inst. M. E. 1863. Page 248.)

Scale 1/50th.

CLAY CROSS PUMPING ENGINE.

Plate 78.

Banging Beams at top of Pit.



(Proceedings Inst. M.E. 1863. Page 248.)

CLAY CROSS PUMPING ENGINE. *Plate 79.*

Indicator Diagrams.

Steam Pressure in Boilers 14 lbs. per square inch above atmosphere.

Fig. 37. *Steam cut off at 71 per cent. of stroke.*

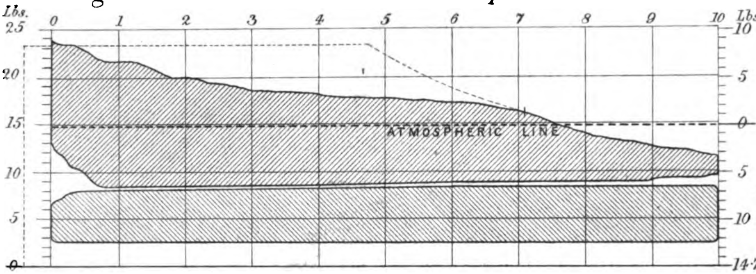


Fig. 38. *Steam cut off at 82 per cent. of stroke.*

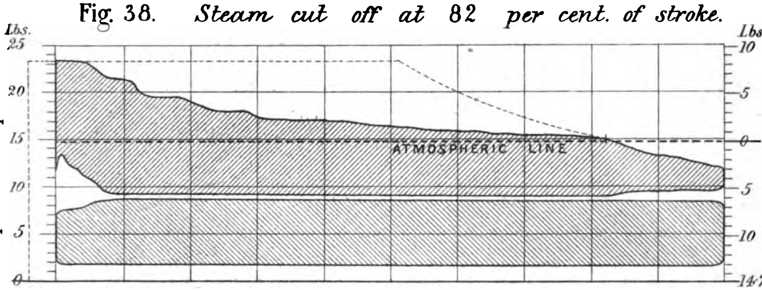


Fig. 39. *Steam cut off at 84 per cent. of stroke.*

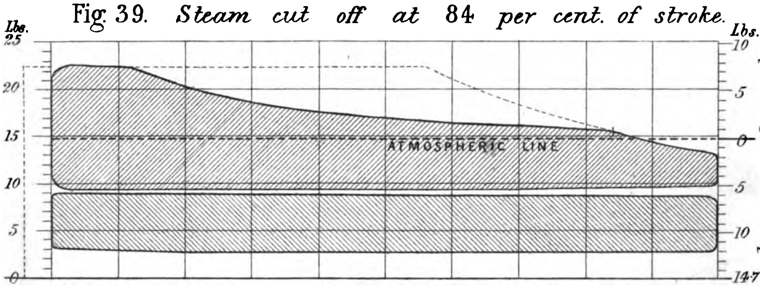
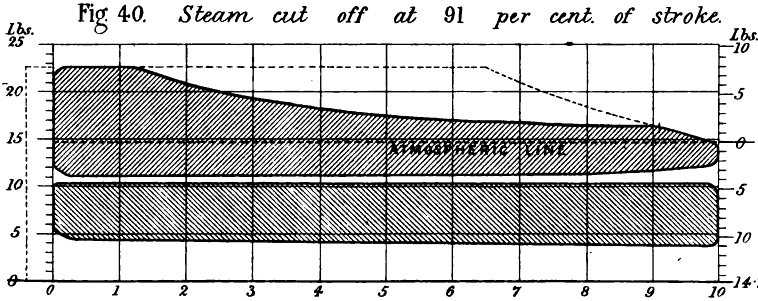


Fig. 40. *Steam cut off at 91 per cent. of stroke.*



Total Pressure, lbs. per square inch.

Pressure lbs. per square inch above atmosphere,

(Proceedings Inst. M. E. 1863. Page 248.)

Melting Furnace.

Fig. 1. Transverse Section.

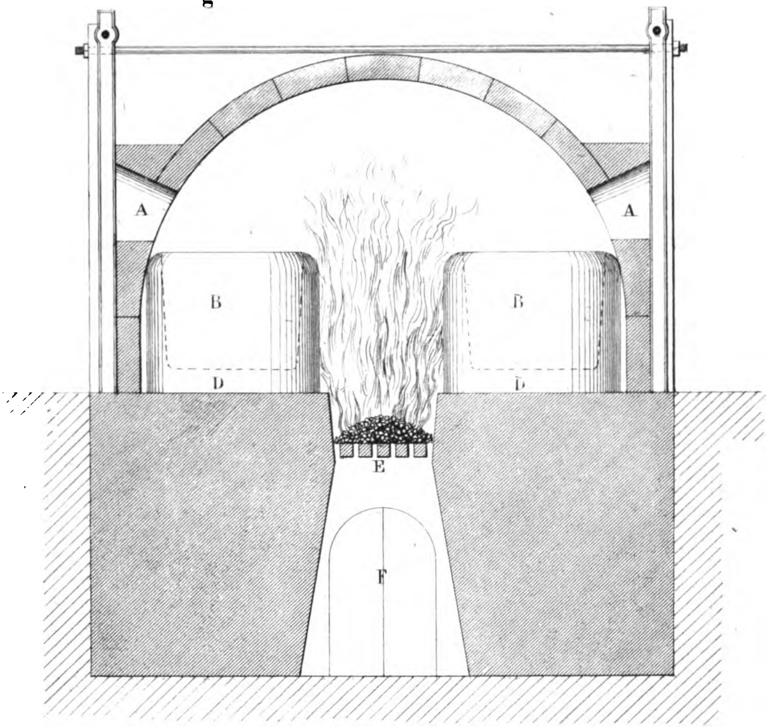
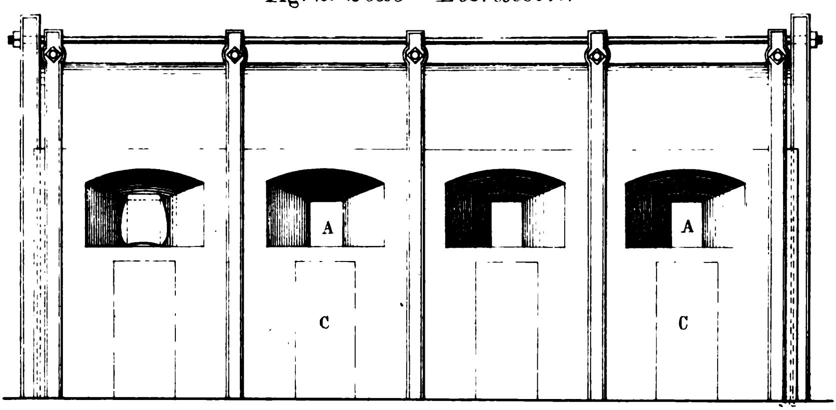


Fig. 2. Side Elevation.



(Proceedings Inst. M.E. 1863. Page 268) Scale 1/80 th.

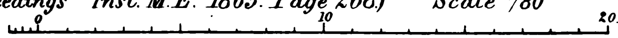


Fig. 3. *Blow-Pipe.*

Fig. 4. *Solid Gathering.*

Fig. 5. *Drawing Out.*

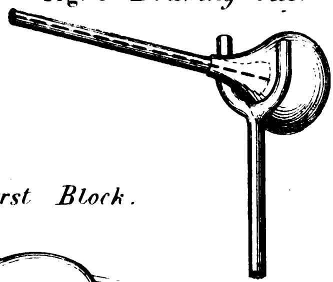


Fig. 6. *First Block.*

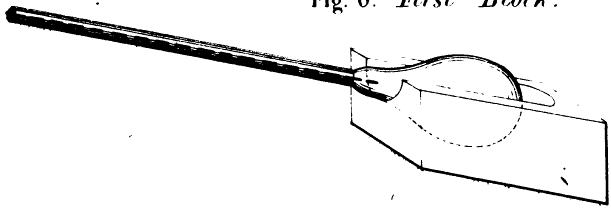


Fig. 7. *Second Block.*

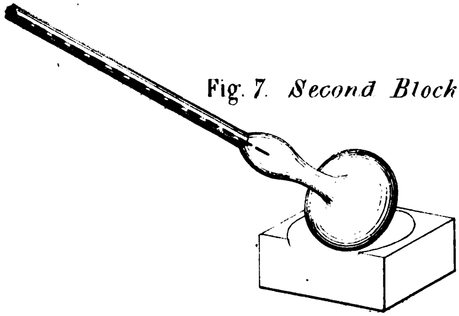
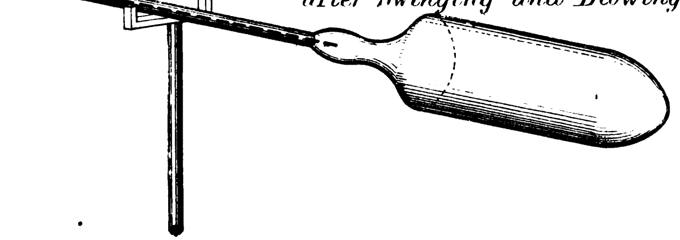


Fig. 8. *Hollow Cylinder after Swinging and Blowing.*



 Scale 1/20th.

POLISHED SHEET GLASS.

Fig. 9. Flashing Outer end of Cylinder.

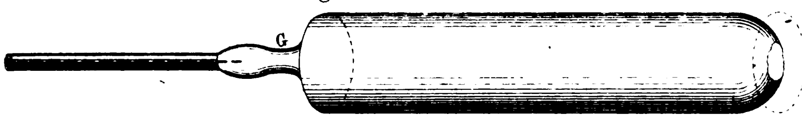


Fig. 10. Breaking off Blow-pipe end of Cylinder.

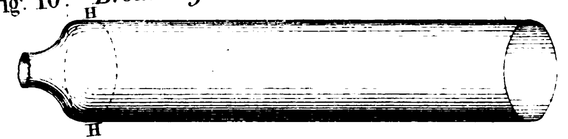


Fig. 12. Splitting Cylinder longitudinally.

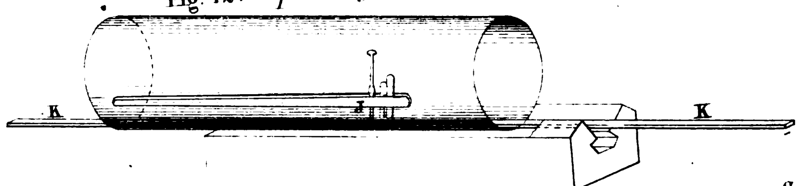
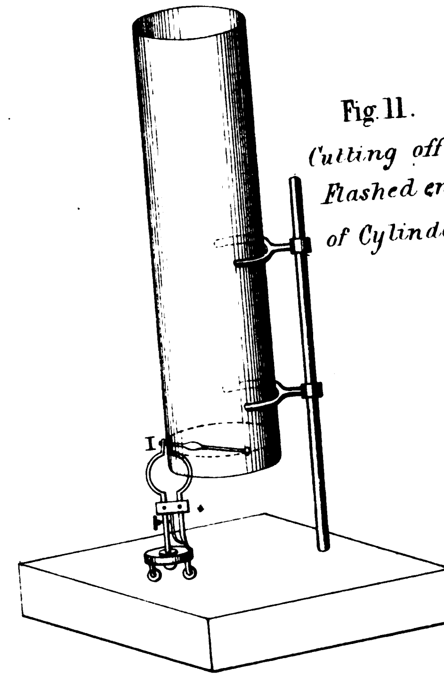


Fig. 11. Cutting off Flashed end of Cylinder.



Scale 1/20th

(Proceedings Inst. M. E. 1863. Page 268.)

Fig. 13. *Flattening and Annealing Kiln.*

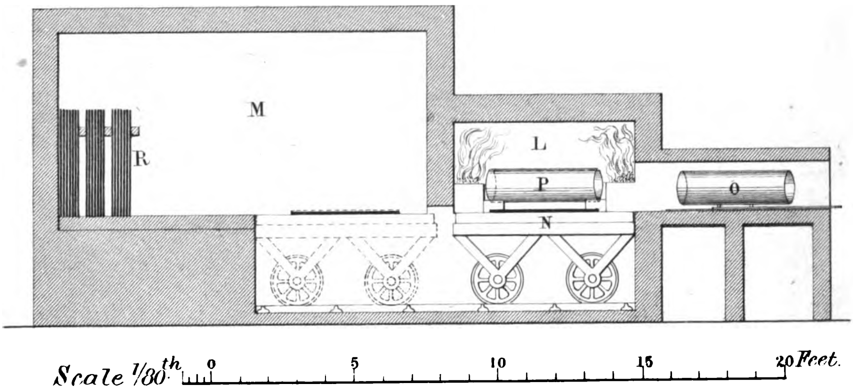
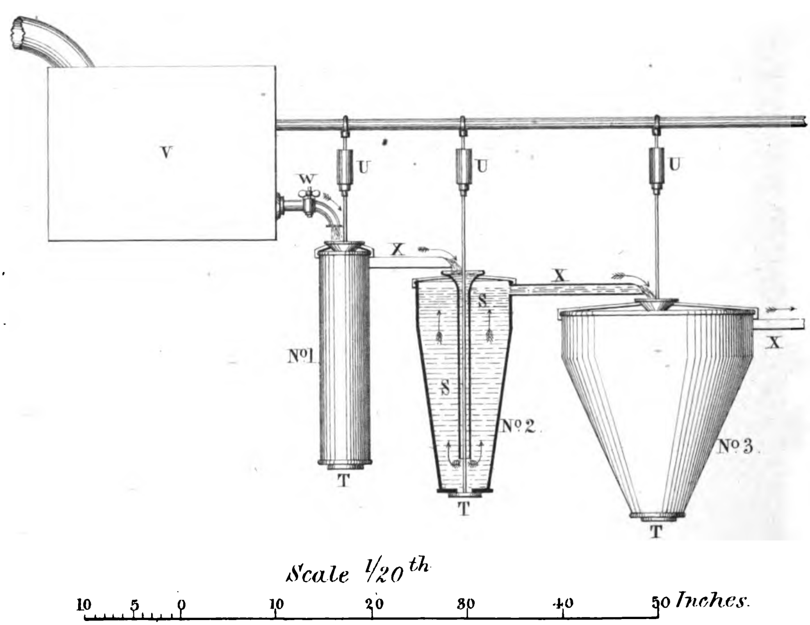


Fig. 14. *Emery Sorting Apparatus.*



(Proceedings Inst. M. E. 1863. Page 268.)